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DETERMINATION OF RESIDENTIAL WOODBURNING IMPACTS IN ONTARIO COMMUNITIES PHASE I: SOURCE PROFILE MEASUREMENTS

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Prepared for

ONTARIO MINISTRY OF THE ENVIRONMENT

Prepared by

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Prepared by

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ACKNOWLEDGEMENT AND DISCLAIMER

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1 INTRODUCTION

The increased use of residential wood combustion in Ontario and several other areas of North America has resulted in adverse air quality impacts in some areas. A recent literature review of such impacts and the legislative approaches directed at minimising air quality impacts (Concord Environmental Corporation, 1989), pointed to the need for the characterization of the organic and inorganic components in residential wood stove emissions from typical firewoods and stoves used in Ontario (Phase I), and the conduct of an air monitoring study in selected wood burning communities in Ontario (Phase II). The source characterization study will be followed by a monitoring program designed to indicate the ambient air quality impacts of residential woodburning in selected communities in Ontario.

Most of the earlier work on source characterization focused on inorganic components and organic carbon. Recently, source profile information on organic components, especially polynuclear aromatic compounds has been determined (Core et al., 1989). The influence of stove type, fuel (wood) type and condition, and of woodstove operating conditions on source profiles represent formidable challenges in reliably characterizing source profiles. Source testing in the present study was designed to measure emissions during steady state burning using three stove commonly used in Ontario and using maple, birch and jackpine firewood - three of the commonly used firewoods in Ontario.

This report describes the results of the source testing of emissions from three wood stoves (designated A, B and C) and three types of wood. The primary objective of the testing is to obtain source profiles (for organic and inorganic species) for three typical fire woods and wood stoves used in Ontario. Source testing was completed in mid-September and comprises the first of a two phase study. The second phase will involve ambient monitoring in three woodburning communities in Ontario over the winter of 1992/1993.

2 EXPERIMENTAL METHODS

The objective of this source characterization study was to obtain source profiles (for organic and inorganic species) for three typical firewoods and residential wood stoves used in Ontario. To meet this objective, an emission testing program was conducted during the period May to September 1991. Three popular wood stoves (designated A, B and C) were tested using three commonly used firewoods, namely: jack pine, maple and white birch. A total of 26 tests were conducted, including 20 test runs used for data analysis. The six tests not included in the data analysis included preliminary tests to establish the range of flue gas velocity and temperature, to establish the sampling strategy and to identify and rectify potential sampling problems. A summary of the sampling matrix is presented in Table 2-1.

A description of the test facility and wood stove configuration, sampling methodology and analytical procedures are presented in the following sections of this chapter.

2.1 DESCRIPTION OF SAMPLING LOCATION AND STOVE OPERATION

All emission tests were conducted at the University of Waterloo, Department of Mechanical Engineering (Solar Laboratory). The laboratory was equipped with an exhaust duct through the roof.

A six (6) inch flue was attached to each stove and the exhaust gases were vented through existing exhaust ducts in the laboratory (see Figure 2-1). Table 2-2 summarizes the specifications of the wood stoves tested. Well seasoned and dried firewood was obtained from commercial suppliers and stored indoors at the test facility.

TABLE 2-1

Sampling Matrix

STOVE TYPE	NUMBER OF VALID TESTS		
	WOOD TYPE		
	PINE	MAPLE	BIRCH
A	3	3 (5)	2 (5)
B	2	2	2
C	2	2 (3)	2

( ) = Numbers in brackets represent the total number of tests conducted including preliminary tests.

TABLE 2-2

Woodstove/Specifications

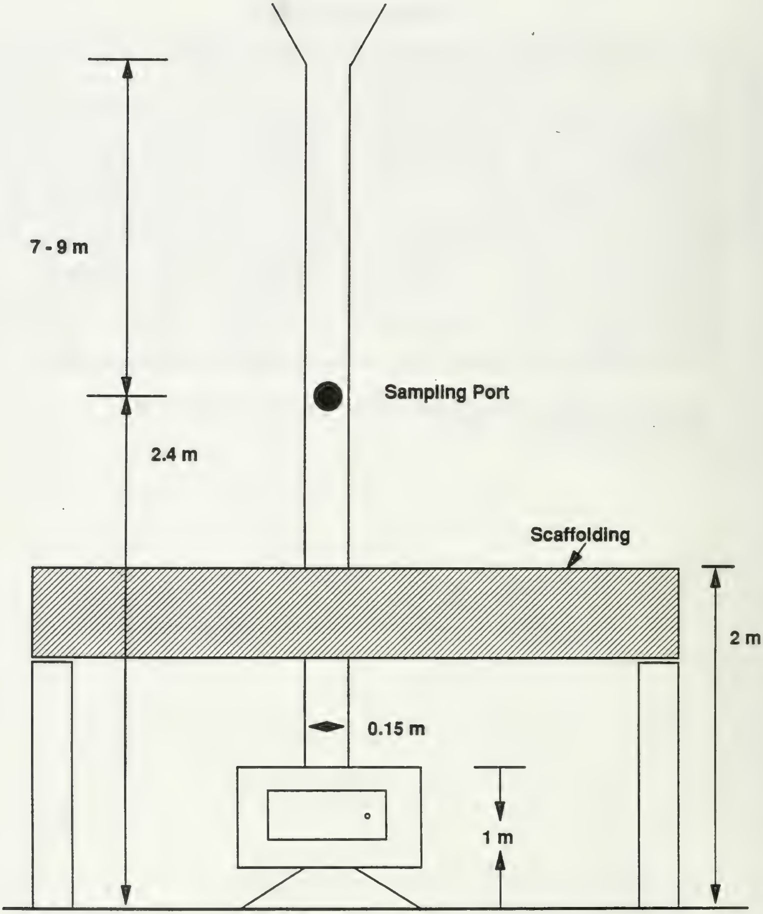
	STOVE		
	A	B	C
Emissions	7.1 grams per hour	3.4 grams per hour	N/A
Width x Depth	24.5 X 25.5 inches	24 x 27.5 inches	25 x 25 inches
Chamber (depth, width, height)	16.5 x 18 x 12 inches	17 x 15.5 x 10.5 inches	13.5 x 21 x 12 inches
Capacity	2.1 cubic feet	1.6 cubic feet	2.0 cubic feet
Heat Output (high heat)**	55,000 BTU	35,000 BTU	30,000 BTU
Duration of Low Fire	9 hours	10-12 hours	N/A
EPA Certification	Yes	Yes	No

**As rated by manufacturer. Actual performance will vary with wood type, moisture content, altitude, chimney and weather conditions.

N/A Not available

FIGURE 2-1

Sampling Location



The stack emissions were sampled using a semi-volatile organic sampling train (SVOC). Sampling was conducted non-isokinetically at a single point on the flue exhaust stack at a height of 2.4 meters above the base of the stove.

The inside stack diameter was six (6) inches (0.15 m). Isokinetic sampling was not achievable since the stack velocities from the wood stoves were so low (typically less than 2 m/s). However, isokineticity is not relevant to gaseous species and fortunately, the particle size distribution of woodstove emissions is predominantly in the fine fraction (<2.5 µm diameter) thus the requirement for isokinetic sampling can be waived.

Sampling was conducted at an "ideal location" as defined by the Ontario Source Testing Code (i.e., at least 8 stack diameter downstream of a flow disturbance and at least 2 stack diameters upstream of a flow disturbance). Table 2-3 lists the various organic and inorganic species measured in the stack emissions.

Sample of stack gas were also collected in tedlar bags using a grab sampling technique for analysis of CO and CO_2. These data were collected for information purposes only and potentially could indicate the completeness of combustion; without comparable data limited use can be made of these data. Grab samples are of limited use in establishing the completeness of combustion throughout the run.

For each test, the following lighting/operating procedures were used:

(i) Five (5) standard logs were placed inside the stove so as not to impede circulation of air and gases within the stove.

(ii) Newspaper was rolled into a tight tube and placed under the wood.

(iii) The newspaper was lit and the stove door was opened to allow adequate quantities of air to enter the stove.

TABLE 2-3

List of Chemical Species Measured In Woodstove Emissions

ORGANIC SPECIES	SYMBOL	INORGANIC SPECIES	SYMBOL
Fluorene	FLOR	Silver	Ag
Dibenzothiophene	DIBE	Aluminum	Al
Phenanthrene	PHEN	Bismuth	Bi
Anthracene	ANTH	Boron	B
Acridine	ACRI	Barium	Ba
Carbazole	CARB	Beryllium	Be
Fluoranthene	FLUO	Cadmium	Cd
Pyrene	PYRE	Calcium	Ca
Retene	RETE	Cobalt	Co
Tetracosane	TETR	Chromium	Cr
Pentacosane	PENT	Copper	Cu
Chrysene	CHRY	Iron	Fe
Hexacosane	HEXA	Potassium	K
Octacosane	OCTA	Manganese	Mn
Benzo(b+k)fluoranthene	BEPF	Molybdenum	Mo
Nonacosane	NONA	Nickel	Ni
Benzo(e)pyrene	BEEP	Lead	Pb
Benzo(a)pyrene	BAP	Tin	Sn
Perylene	PERY	Titanium	Ti
Indeno(1,2,3-cd)pyrene	INDE	Vanadium	V
Dibenzo(a,h)anthracene	DIAA	Zinc	Zn
Benzo(ghi)perylene	BEGP		
COMBUSTION GAS			
Carbon Monoxide	CO		
Carbon Dioxide	CO_2		

(iv) Once the wood appeared to be burning on its own the stove door was closed and secured.

(v) The stove was allowed to reach a steady state condition representing steady burning conditions. The flue gas temperature was monitored and used as an indicator of steady state combustion in the stove. For each test, flue gas temperature was maintained to ±20 °F by adjustment of the dampers on the stove or by adding logs. Fluctuations outside of the (arbitrary) limit of ±20 °F occurred for a short time when a log was added.

(vi) Logs were added to the stoves and dampers adjusted during the test on an as-required basis. Sampling continued during these activities.

2.2 SAMPLING METHOD

Stack gas samples were collected using a modified method 5 (MM5) sampling train following the protocols outlined in the "Reference Method for Source Testing: Measurement of Releases of Selected Semi-Volatile Organic Compounds (SVOC) from Stationary Sources (Appendix A)", with the following modifications:

a) HPLC grade water was used as the impinger solution instead of ethylene glycol. The use of water or ethylene glycol is consistent with OME (Air Resources Branch) practise for stack sampling where the two solvents are considered equivalent.

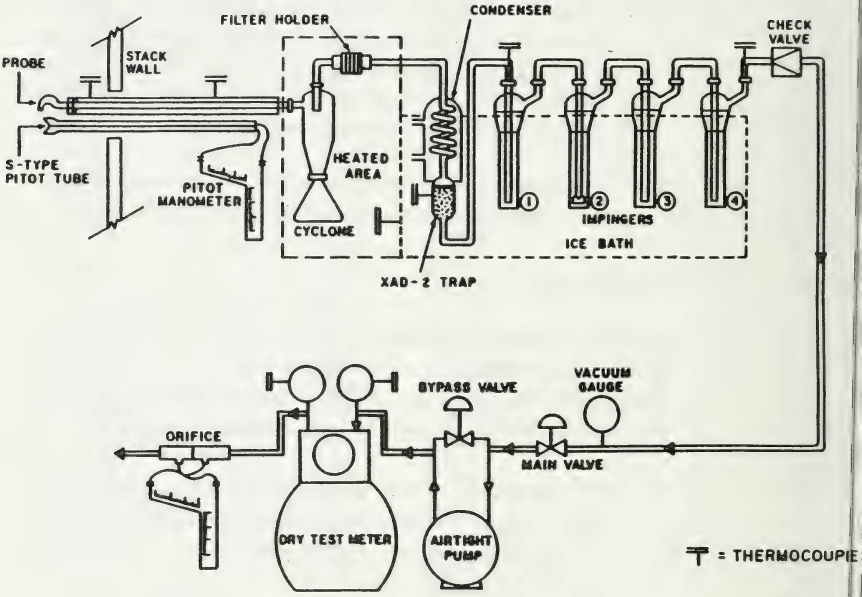
b) The second impinger contained 100 mL of HPLC grade water.

c) Single point, non-isokinetic sampling was carried out.

A schematic of the MM5 sampling train is shown in Figure 2-2.

FIGURE 2-2

Sampling Train Configuration



IMPINGER CONTENTS	FILTER	RESIN
1. HPLC WATER	1. WHATMAN GLASS FIBRE	1. XAD-2
2. HPLC WATER		
3. EMPTY		
4. SILICA GEL		

The sampling train consisted of a removable glass sampling tube liner inserted into a three (3) foot stainless steel probe with a nickel plated sampling nozzle attached to the end of the glass liner. The entire outside length of the glass liner was wrapped with heat tape and the probe was maintained at a temperature of 120°C ± 14°C. An S-type pitot tube was attached to the outside of the probe. The stack gas velocity was measured using a digital micromanometer.

After the probe, the gas passed through a heated glass fibre filter. Downstream of the heated filter, the sample gas passed through a water-cooled module, then through a sorbent module containing approximately 30 to 40 g of XAD-2 resin (pack trap). The XAD-2 module, which was kept at a temperature below 20°C, was followed by a series of four impingers. The first impinger was connected to the outlet of the XAD-2 module and contained 100 mL of HPLC grade water. The second impinger also contained 100 mL of HPLC grade water, the third impinger was empty and the fourth impinger contained a known weight of silica gel.

The impingers, condenser and XAD-2 resin module were weighed prior to assembling the train to permit gravimetric moisture determination of the stack gas.

All connections within the train were glass or Teflon and no sealant greases were used. The impingers are followed by a control box containing a pump, dry gas meter and calibrated orifice.

Prior to sampling, all train glassware was washed with laboratory soap (Alconox) and water and thoroughly rinsed with HPLC grade water, pesticide grade hexane and pesticide grade acetone.

Pre-test quality checks of solvents, filters, sorbent (XAD-2) and train glassware were performed prior to the initiation of the tests. All target analyte compounds had acceptable blank levels.

Single point, non-isokinetic sampling was carried out for approximately 50 to 80 minutes to allow collection of sufficient cumulative flue gas volume to perform necessary analyses about 0.6 to 1 DSCM (dry standard cubic meter).

Readings of flue gas parameters and all necessary sampling train parameters were recorded at every 5 minute increment throughout the test. The following information was recorded:

- sampling time,
- dry gas meter volume,
- pitot tube pressure,
- stack gas temperature,
- probe, oven, XAD-2 module and impinger temperature,
- dry gas meter temperature,
- control module orifice pressure, and
- sampling pump vacuum pressure.

During the sampling, the XAD-2 module was maintained below 20°C to ensure efficient collection of target compounds by the XAD-2 adsorbent cartridge. The water in the impinger box was maintained below 5°C by frequent addition of ice to the box.

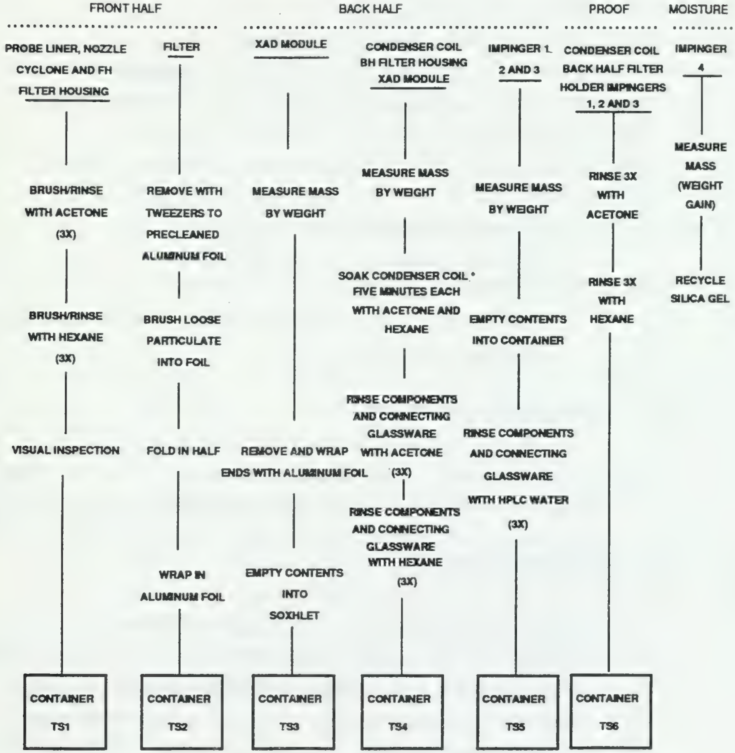
Leak checks on the MM5 sampling train were performed before and after each sampling run. Sampling did not commence until an acceptable leak rate was achieved (< 0.02 cfm at 15" Hg). Post-test leak checks were conducted at 1 inch Hg vacuum above the maximum vacuum measured during the test.

Following the completion of the test, the sampling train was transported to the laboratory at Concord. During transport and storage, the sample train components (except the probe and nozzle) were maintained at 4°C.

Train samples were recovered following the protocol outlined in Figure 2-3.

FIGURE 2-3

Trace Organic Sampling Train Recovery Procedure


FRONT HALF
BACK HALF
PROOF
MOISTURE
PROBE LINER, NOZZLE CYCLONE AND FH FILTER HOUSING
BRUSH/RINSE WITH ACETONE (3X)
BRUSH/RINSE WITH HEXANE (3X)
VISUAL INSPECTION
CONTAINER TS1
FILTER
REMOVE WITH TWEEZERS TO PRECLEANED ALUMINUM FOIL
BRUSH LOOSE PARTICULATE INTO FOIL
FOLD IN HALF
WRAP IN ALUMINUM FOIL
CONTAINER TS2
XAD MODULE
MEASURE MASS BY WEIGHT
REMOVE AND WRAP ENDS WITH ALUMINUM FOIL
EMPTY CONTENTS INTO SOXHLET
CONTAINER TS3
CONDENSER COIL BH FILTER HOUSING XAD MODULE
MEASURE MASS BY WEIGHT
SOAK CONDENSER COIL * FIVE MINUTES EACH WITH ACETONE AND HEXANE
RINSE COMPONENTS AND CONNECTING GLASSWARE WITH ACETONE (3X)
RINSE COMPONENTS AND CONNECTING GLASSWARE WITH HEXANE (3X)
CONTAINER TS4
IMPINGER 1 2 AND 3
MEASURE MASS BY WEIGHT
EMPTY CONTENTS INTO CONTAINER
RINSE COMPONENTS AND CONNECTING GLASSWARE WITH HPLC WATER (3X)
CONTAINER TS5
CONDENSER COIL BACK HALF FILTER HOLDER IMPINGERS 1, 2 AND 3
RINSE 3X WITH ACETONE
RINSE 3X WITH HEXANE
CONTAINER TS6
IMPINGER 4
MEASURE MASS (WEIGHT GAIN)
RECYCLE SILICA GEL

* MARK ALL LIQUID LEVELS
* CONTINUE CHAIN OF CUSTODY
* SEAL LIDS WITH APPROPRIATE TAPE

* CONDENSER COIL SOAKING STEP PERFORMED BY LAB PERSONNEL AFTER XAD RESIN REMOVED

TS1 AND TS2 SAMPLES COMBINED FOR FRONT HALF ANALYSIS
TS3 TS4, AND TS5 SAMPLES COMBINED FOR BACK HALF ANALYSIS
TS6 SAMPLE ARCHIVED FOR POSSIBLE FUTURE ANALYSIS, IF REQUIRED

Six train samples (TS) were obtained during each run:

TS1	-	acetone/hexane front half rinsings
TS2	-	filter
TS3	-	XAD-2 resin
TS4	-	back half acetone/hexane rinsings
TS5	-	impinger solutions and HPLC grade water rinsings
TS6	-	Proof rinse - acetone/hexane rinsings of all train glassware

Samples were combined as follows for sample extraction and analysis:

- TS1 and TS2 combined for front half analysis.
- TS3, and TS4 combined for back half analysis.
- TS5 analyzed separately.
- TS6 archived for possible future analysis if required (proof/recovery efficiency check sample).

2.3 ANALYTICAL PROCEDURES

The samples collected during this study were analyzed for 24 organic compounds by Gas Chromatography/Mass Selective Detector (GC/MSD) and one half of the filter for inorganics (21 elements) by Inductively Coupled Plasma Atomic Emission Spectroscopy (ICAP).

The organic analysis involved complex sample extraction and clean-up procedures. To monitor the extraction, clean-up and analysis of the organic samples, labelled surrogate standards (d12-chrysene and d10-phenanthrene) were added to the samples and blanks prior to extraction. Two performance standards (fluoranthene and d12 benzo(ghi)perylene) were used to monitor GC/MSD and operator variability. A copy of the sample extraction, clean-up and analytical procedure for organic analysis is provided in Appendix A.

Before extraction and analysis of real train samples were performed, a series of recovery tests were conducted to evaluate the performance of the extraction and clean-up procedures.

Six samples (XAD-2, HPLC grade water and glass fibre filter in duplicate) were spiked with 15,000 ng of each target compound. The samples were then extracted, clean-up and analyzed following the protocol established for this study. Table 2-4 presents the extraction efficiencies of the target compounds. In general, the recovery efficiencies for the target compounds were greater than 70%. The recovery of acridine was very low (10-16%), which may be attributed to the polarity of acridine. The analytical detection limits (MDL) for organic analyses by GC/MSD were 0.3 µg/sample for all compounds except acridine which was 1.5 µg/sample.

As noted earlier, the sampling train was analyzed for target organic compounds in three fractions as follows:

FRACTION 1 -	Front-half rinsings (TS1) and 1/2 filter (TS2)
FRACTION 2 -	XAD-2 resin (TS3) and back-half rinsings (TS4)
FRACTION 3 -	Impinger solutions and rinsings (TS5)

Analytical data for each of these fractions are provided in Appendix D.

The other half of the filters were analyzed for inorganics by ICAP following EPA Method 6010. The filters were prepared for analysis following a modified version of NIOSH Method 7800. Copies of the analytical procedures are presented in Appendix A. Laboratory QC data are provided in Appendix D. All inorganic data were filter blank corrected.

TABLE 2-4

Extraction Efficiencies

		XAD					WATER					FILTER				
	Std Spiked	Blank	Spike 1	Spike 2	Avg	Recov.	Blank	Spike 1	Spike 2	Avg	Recov.	Blank	Spike 1	Spike 2	Avg	Recov.
COMPOUNDS	ng/µL	ng/µL				(%)	ng/µL				(%)	ng/µL				(%)
FLUORENE	5	ND	3.2	4.0	3.6	72.4	ND	2.8	2.3	2.6	51.0	ND	3.2	1.9	2.6	51.0
DIBENZOTHIOPHENE	5	ND	3.2	3.4	3.3	66.4	ND	2.6	2.7	2.7	53.0	ND	2.3	2.3	2.3	46.0
PHENANTHRENE	5	ND	3.6	4.4	4.0	80.0	ND	3.5	3.2	3.4	67.0	ND	3.3	2.9	3.1	62.0
ANTHRACENE	5	ND	3.7	4.2	4.0	79.2	ND	4.1	4.1	4.1	82.0	ND	3.9	3.9	3.9	78.0
ACRIDINE	5	ND	0.7	0.3	0.5	10.2	ND	0.8	0.8	0.8	16.0	ND	0.8	0.8	0.8	16.0
CARBAZOLE	5	ND	2.4	3.9	3.2	63.0	ND	2.5	3.2	2.9	57.0	ND	2.9	2.4	2.7	53.0
FLUORANTHENE	5	ND	3.8	4.7	4.3	85.4	ND	3.6	3.8	3.7	74.0	ND	3.4	3.4	3.4	68.0
PYRENE	5	ND	3.6	4.3	4.0	79.0	ND	3.7	3.8	3.8	75.0	ND	3.4	3.6	3.5	70.0
RETENE	5	ND	3.6	4.2	3.9	78.0	ND	3.6	3.8	3.7	74.0	ND	3.3	3.5	3.4	68.0
TETRACOSANE	5	ND	4.4	5.3	4.9	97.4	ND	5.0	4.6	4.8	96.0	ND	3.9	4.9	4.4	88.0
PENTACOSANE	5	ND	4.7	5.1	4.9	97.8	ND	5.2	4.6	4.9	98.0	ND	4.1	4.9	4.5	90.0
CHRYSENE	5	ND	3.7	4.3	4.0	80.2	ND	3.6	4.1	3.9	77.0	ND	3.4	3.4	3.4	68.0
1,2-BENZANTHRACENE	5	ND	3.6	4.5	4.1	81.0	ND	3.6	4.1	3.9	77.0	ND	3.7	3.5	3.6	72.0
HEXACOSANE	5	ND	4.7	4.8	4.7	94.8	ND	5.2	4.6	4.9	98.0	ND	4.0	4.8	4.4	88.0
OCTACOSANE	5	ND	4.3	4.3	4.3	86.2	ND	5.0	4.5	4.8	95.0	ND	3.9	4.6	4.3	85.0
BENZO(b+k)FLUORANTHENE	10	ND	6.5	8.4	7.4	74.4	ND	11.2	12.8	12.0	120.0	ND	5.4	10.4	7.9	79.0
NONACOSANE	5	ND	4.6	4.0	4.3	85.6	ND	5.4	4.7	5.1	101.0	ND	4.2	4.9	4.6	91.0
BENZO(e)PYRENE	5	ND	3.7	3.0	3.4	67.2	ND	3.6	4.1	3.9	77.0	ND	3.4	3.3	3.4	67.0
BENZO(a)PYRENE	5	ND	3.7	4.0	3.9	77.2	ND	3.5	4.1	3.8	76.0	ND	3.4	3.3	3.4	67.0
PERYLENE	5	ND	3.7	4.1	3.9	78.2	ND	3.4	4.0	3.7	74.0	ND	3.1	3.1	3.1	62.0
INDENO(1,2,3-c,d)PYRENE	5	ND	4.2	4.7	4.5	89.0	ND	3.7	4.2	4.0	79.0	ND	3.7	3.3	3.5	70.0
DIBENZO(a,h)ANTHRACENE	5	ND	4.2	4.7	4.5	89.0	ND	3.6	4.2	3.9	78.0	ND	3.7	3.2	3.5	69.0
BENZO(ghi)PERYLENE	5	ND	4.2	4.7	4.5	89.0	ND	3.8	4.2	4.0	80.0	ND	3.6	3.3	3.5	69.0
Surrogates																
d10-PHENANTHRENE	5	ND	3.2	4.0	3.6	72.4	ND	6.6	6.0	6.3	97.0	ND	3.2	2.7	3.0	76.0
d12-CHRYSENE	5	ND	7.2	8.6	7.9	89.0	ND	3.4	3.9	3.7	73.0	ND	6.8	6.7	6.8	84.0

ND = Not detected

3 RESULTS AND DISCUSSION

Analytical data for the source characterization are presented in this section. The organic compounds were analyzed in three fractions namely, a) the acetone/hexane front half rinse and filter, b) the XAD-2 resin and back half rinsings and c) the impinger solutions. The total mass of each component in the sample was calculated by summing the masses in each of the three fractions analyzed after correcting for the analysis of one-half of the filter. The inorganic species were determined by ICAP analysis of one half of the filter.

The concentration of each species in the flue gas was calculated from the total mass and the corrected (to standard dry gas volume at 25 °C and 1 atmosphere) sample volume. The source profiles are expressed as the ratio of each component relative to the concentration of benzo(e)pyrene (designated as BEEP in tables and figures). BEEP was selected as the reference compound for both organic and inorganic compounds because of its stability and presence in all samples and also because it has been used similarly in reviewing woodstove emissions (Daisey et al., 1986).

3.1 DISTRIBUTION OF ANALYTES IN SAMPLES

There were negligible amounts of analytes in the probe rinse and impinger fraction; the majority of the constituents were present in the resin (details are given in Appendix D). The negligible amount in the probe and impinger fraction is consistent with the particle size distribution of woodstove emissions. The larger particles would be deposited in the probe especially since sampling was non-isokinetic. Since the analysis of the probe rinse together with the impinger solution yielded minor amounts of organics, then most of the organic species are present in the vapour phase or in the fine particles which are deposited on the filter. Negligible amounts of organics are present in any larger particles which may have been deposited in the probe.

Discussion of the distribution of the organic components between the filter and the resin is not pursued in detail because subsequent monitoring data will combine the extracts from the resin in a backup sorbent with the extract from filter in the sampler. Also, the distribution of the organic components between the vapour and particle phases is difficult to determine reliably; for example, for the semivolatile PAH, changes in the phase distribution may occur during sampling as material deposited initially as particles can be vaporized during subsequent sampling. Comparisons of the source profiles obtained in this study with those obtained elsewhere will take this aspect into consideration (see Section 3.4).

3.2 SUMMARY OF RESULTS BY STOVE TYPE

Table 3-1 summarizes the average concentrations (with their standard deviations) of organic and inorganic species for each of the three stoves used. Included in the tables are species numbers (column Spec. #) which are the numbers used in EPA source profiles thus comparison with EPA source profiles will be facilitated. The symbols for each compound are indicated also and will facilitate examination of the graphs since the symbols for the most part are mnemonic. Table 3-1A lists the average concentrations and the standard deviation based on two or three replicate tests; in contrast, Table 3-1B lists the average ratios and the standard deviation in the average ratios - calculated by determining the ratio for each compound in each run then averaging the ratios. Note that the average ratios in Table 3-1B are not the ratio of the average concentration to that of the average concentration of BEEP but rather are the averages of the ratios. Details of the individual and average test data as well as ratios to BEEP are listed by stove type and wood type in Appendix B. Figures 3-1 and 3-2 show respectively, the organic and inorganic source profiles for the three stoves. Source profiles are illustrated relative to benzo(e)pyrene. In view of the large range in the ratio for various species, the scales in Figures 3-1 and 3-2 (and also in subsequent figures) are logarithmic. Ratios less than 0.01 are not shown in these figures for clarity but are listed in the tables.

TABLE 3-1A

Average Concentration of Organic and Inorganic Species Produced by Each Wood Stove Regardless of Wood Type

STOVE TYPE			A			B			C		
	Symbol	Spec. #	Average Concentration		Standard Deviation	Average Concentration		Standard Deviation	Average Concentration		Standard Deviation
ORGANICS			(µg/m3)			(µg/m3)			(µg/m3)		
Fluorene	FLOR	222	131.0	±	128.3	287.8	±	136.6	283.5	±	382.4
Dibenzothiophene	DIBE	221	1.9	±	4.3	1.8	±	2.7	7.3	±	15.9
Phenanthrene	PHEN	231	189.1	±	185.5	231.4	±	227.8	241.2	±	346.8
Anthracene	ANTH	211	64.6	±	107.0	25.4	±	42.9	282.6	±	473.2
Acridine	ACRI	210	75.4	±	227.1				104.2	±	203.0
Carbizole	CARB	218	3.7	±	4.0	4.8	±	6.6	36.3	±	86.1
Fluoranthene	FLUO	223	222.6	±	169.9	243.8	±	168.4	380.9	±	475.5
Pyrene	PYRE	232	299.6	±	269.0	333.2	±	218.4	514.8	±	798.4
Retene	RETE	233	19.4	±	46.3	97.0	±	200.2	470.1	±	1198.8
Tetracosane	TETR	234	6.1	±	8.8	2.0	±	2.1	3.9	±	7.2
Pentacosane	TRIA	235	8.6	±	12.8	11.0	±	19.4	1.5	±	4.0
Chrysene	CHRY	219	160.1	±	220.1	163.4	±	85.6	422.3	±	625.7
1,2-Benzanthracene	BZA		222.6	±	320.6	207.3	±	85.0	487.2	±	827.4
Hexacosane	HEXA	225	23.0	±	45.6	4.1	±	5.4	5.8	±	8.3
Octacosane	OCTA	228	6.8	±	9.2	3.4	±	2.2	0.8	±	2.1
Benzo(b+k)Fluoranthene	BEBF	213	317.8	±	358.7	433.2	±	166.6	380.4	±	366.8
Nonacosane	NONA	227	6.8	±	8.6	2.7	±	2.4	0.9	±	1.6
Benzo(e)Pyrene	BEEP	215	143.8	±	274.1	85.0	±	21.4	188.4	±	235.3
Benzo(a)Pyrene	BAP	212	163.3	±	265.7	154.5	±	62.6	258.3	±	379.4
Perylene	PERY	230	35.8	±	56.0	31.7	±	9.9	60.8	±	62.3
Indeno(1,2,3-c,d)Pyrene	INDE	226	171.2	±	340.0	79.8	±	17.1	247.8	±	219.2
Dibenzo(a,h)Anthracene	DIAA	220	35.7	±	75.1	30.8	±	5.0	73.0	±	87.8
Benzo(ghi)Perylene	BEGP	216	213.1	±	463.5	92.5	±	22.9	287.4	±	241.3
INORGANICS											
Silver	Ag	47	0.1	±	0.2	0.4	±	0.6			
Aluminum	Al	13	243.7	±	503.4				507.6	±	959.5
Bismuth	Bi	83									
Boron	B	5	175.6	±	390.1	195.9	±	229.3	636.3	±	1148.5
Barium	Ba	56	400.1	±	849.6	94.4	±	227.1	943.9	±	1798.9
Beryllium	Be	4	0.1	±	0.3				0.3	±	0.5
Cadmium	Cd	48	9.9	±	6.5	5.8	±	5.1	6.9	±	7.3
Calcium	Ca	20	51.0	±	120.7	7.5	±	16.4	146.5	±	248.8
Cobalt	Co	27				3.5	±	2.3	2.2	±	1.5
Chromium	Cr	24	0.7	±	0.5	0.5	±	0.3	0.3	±	0.4
Copper	Cu	29	2.4	±	2.3	1.6	±	0.8	3.4	±	3.6
Iron	Fe	26	6.9	±	8.7	7.1	±	5.3	10.3	±	12.9
Potassium	K	19	1409.7	±	1401.8	2585.6	±	2508.4	3517.7	±	2374.0
Manganese	Mn	25	8.8	±	6.1	10.5	±	8.2	14.4	±	12.8
Molybdenum	Mo	42									
Nickel	Ni	28	1.4	±	2.2				2.5	±	5.5
Lead	Pb	82	29.8	±	27.4	14.5	±	12.5	21.9	±	25.0
Tin	Sn	50									
Titanium	Ti	22									
Vanadium	V	23									
Zinc	Zn	30	857.3	±	1105.4	392.4	±	452.6	1250.1	±	1981.5

TABLE 3-1B

Average Ratios Of Organic and Inorganic Species to BEEP Produced By Each Wood Stove Regardless Of Wood Type

STOVE TYPE			A			B			C		
	Symbol	Spec. #	Average Ratio to BEEP		Standard Deviation	Average Ratio to BEEP		Standard Deviation	Average Ratio to BEEP		Standard Deviation
ORGANICS											
Fluorene	FLOR	222	2.16E+00	±	1.44E+00	3.31E+00	±	9.05E-01	2.12E+00	±	1.84E+00
Dibenzothiophene	DIBE	221	1.16E-02	±	1.79E-02	1.93E-02	±	2.94E-02	2.20E-02	±	3.16E-02
Phenanthrene	PHEN	231	6.66E+00	±	9.30E+00	2.64E+00	±	2.57E+00	1.34E+00	±	1.18E+00
Anthracene	ANTH	211	1.53E+00	±	1.74E+00	3.03E-01	±	5.05E-01	1.74E+00	±	1.64E+00
Acridine	ACRI	210	2.30E-01	±	4.62E-01				7.39E-01	±	1.59E+00
Carbizole	CARB	218	2.74E-01	±	6.64E-01	4.89E-02	±	5.98E-02	1.28E-01	±	1.76E-01
Fluoranthene	FLUO	223	5.66E+00	±	5.51E+00	2.84E+00	±	1.67E+00	3.63E+00	±	3.77E+00
Pyrene	PYRE	232	4.89E+00	±	3.90E+00	3.74E+00	±	2.02E+00	3.33E+00	±	2.03E+00
Retene	RETE	233	1.63E-01	±	2.90E-01	1.49E+00	±	3.18E+00	1.78E+00	±	2.62E+00
Tetracosane	TETR	234	6.15E-01	±	1.60E+00	2.00E-02	±	1.94E-02	8.80E-03	±	1.50E-02
Pentacosane	TRIA	235	7.36E-01	±	1.70E+00	1.26E-01	±	2.30E-01	1.82E-02	±	4.89E-02
Chrysene	CHRY	219	1.69E+00	±	5.57E-01	1.89E+00	±	6.35E-01	2.82E+00	±	2.25E+00
1,2-Benzanthracene	BZA		2.14E+00	±	7.44E-01	2.43E+00	±	6.32E-01	3.71E+00	±	3.58E+00
Hexacosane	HEXA	225	7.46E+00	±	2.21E+01	4.17E-02	±	5.26E-02	8.94E-02	±	1.78E-01
Octacosane	OCTA	228	3.90E-01	±	7.20E-01	4.08E-02	±	2.51E-02	9.64E-03	±	2.59E-02
Benzo(b+k)Fluoranthene	BEBF	213	4.54E+00	±	2.05E+00	5.22E+00	±	1.81E+00	3.75E+00	±	3.29E+00
Nonacosane	NONA	227	5.65E-01	±	1.31E+00	3.08E-02	±	2.61E-02	6.19E-02	±	1.54E-01
Benzo(e)Pyrene	BEEP	215	1.00E+00	±	0.00E+00	1.00E+00	±	0.00E+00	1.00E+00	±	0.00E+00
Benzo(a)Pyrene	BAP	212	1.45E+00	±	2.58E-01	1.79E+00	±	3.84E-01	1.63E+00	±	1.50E+00
Perylene	PERY	230	3.01E-01	±	1.63E-01	3.72E-01	±	5.63E-02	3.67E-01	±	1.52E-01
Indeno(1,2,3-c,d)Pyrene	INDE	226	1.56E+00	±	6.68E-01	9.53E-01	±	1.34E-01	2.47E+00	±	3.44E+00
Dibenzo(a,h)Anthracene	DIAA	220	3.52E-01	±	3.86E-01	3.76E-01	±	9.52E-02	5.72E-01	±	7.55E-01
Benzo(ghi)Perylene	BEGP	216	1.50E+00	±	8.15E-01	1.10E+00	±	1.68E-01	3.16E+00	±	5.20E+00
INORGANICS											
Silver	Ag	47	3.64E-02	±	9.67E-02	5.66E-03	±	9.23E-03			
Aluminum	Al	13	8.76E-01	±	1.60E+00				1.91E+01	±	3.90E+01
Bismuth	Bi	83								±	0.00E+00
Boron	B	5	5.08E-01	±	8.96E-01	2.58E+00	±	3.68E+00	2.66E+01	±	5.67E+01
Barium	Ba	56	1.31E+00	±	2.43E+00	1.48E+00	±	3.72E+00	3.49E+01	±	7.06E+01
Beryllium	Be	4	1.49E-04	±	4.00E-04				1.16E-02	±	2.50E-02
Cadmium	Cd	48	4.72E-01	±	6.30E-01	6.72E-02	±	5.44E-02	1.60E-01	±	2.45E-01
Calcium	Ca	20	1.21E-01	±	2.05E-01	1.16E-01	±	2.67E-01	7.97E+00	±	1.94E+01
Cobalt	Co	27				4.64E-02	±	3.36E-02	4.02E-02	±	6.67E-02
Chromium	Cr	24	5.61E-02	±	1.25E-01	5.74E-03	±	4.80E-03	1.19E-02	±	2.66E-02
Copper	Cu	29	1.95E-01	±	3.42E-01	1.93E-02	±	8.60E-03	4.81E-02	±	5.31E-02
Iron	Fe	26	1.83E-01	±	4.21E-01	8.61E-02	±	5.68E-02	3.25E-01	±	6.53E-01
Potassium	K	19	2.41E+01	±	1.94E+01	2.78E+01	±	2.45E+01	6.39E+01	±	6.80E+01
Manganese	Mn	25	1.53E+00	±	3.72E+00	1.39E-01	±	1.22E-01	5.98E-01	±	1.31E+00
Molybdenum	Mo	42									
Nickel	Ni	28	2.09E-02	±	4.68E-02				2.94E-02	±	5.04E-02
Lead	Pb	82	1.17E+00	±	1.54E+00	1.63E-01	±	1.25E-01	3.25E-01	±	3.27E-01
Tin	Sn	50									
Titanium	Ti	22									
Vanadium	V	23									
Zinc	Zn	30	2.34E+01	±	5.47E+01	4.83E+00	±	5.59E+00	3.20E+01	±	5.40E+01

FIGURE 3-1

Organic Source Profiles (Relative to BeP) for Three Stove Types

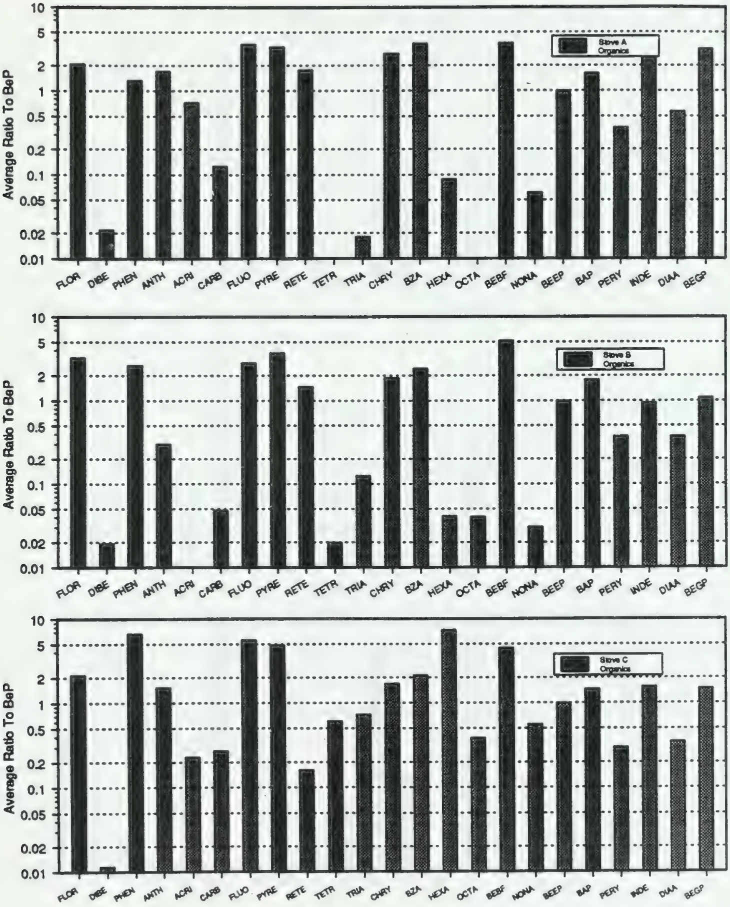
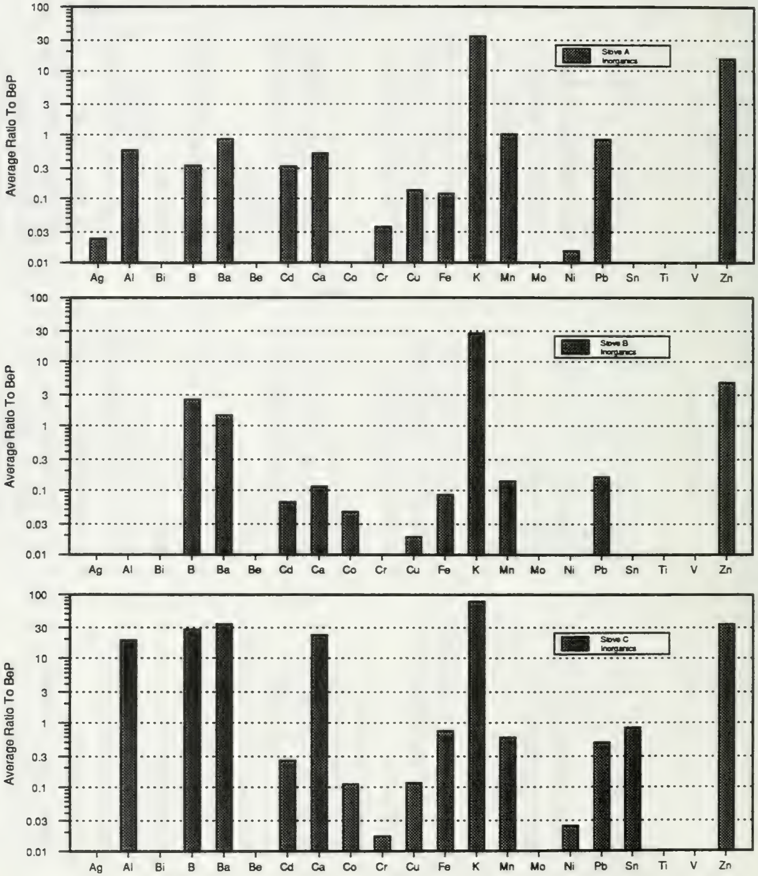


FIGURE 3-2

Inorganic Source Profiles (Relative to BeP) for Three Stove Types



The concentrations for organic species were generally higher than for inorganic species with the notable exceptions of K, Zn and Ba and B. Of the 23 organic species selected for analysis, all except one (acridine) were found in all samples. The detection limits for all organic species was 0.3 µg/sample except for acridine which was 1.5 µg/sample. The higher detection limit and the low recovery for acridine (10 to 16% compared with over 70% for other organics) indicate that the data for acridine should be used with caution.

Twenty-one (21) inorganic elements were selected for analysis. Five elements (Bi, Mo, Sn, Ti and V) were not detected at all in any sample, while Ag, Al, Be, Co and Ni were not detected in emissions from one stove type. The amounts of Al, B, Ba and Ca found on some filters were not very different from blank levels, i.e., blanks were considered relatively high. Occasionally, inexplicable non detection of analytes occurred for one of two replicate samples, e.g., Fe or Zn not detected in one of two or three replicate samples.

Before discussing the variability in the data, it must be noted that the measurements were designed to determine source profiles (as opposed to emission factors) hence determination of the amount of excess air and of flow rates of the exhaust gases were not measured. In order to maintain as constant burn as practicable, the dampers in the stoves were adjusted (thereby varying the amount of air and the flow rate) to maintain as constant a temperature as possible. As a result of this, the concentrations in the flue gases are dependent on the amount of excess air and are thus not expected to be consistent. In contrast, the ratios of the analytes - relative to BEEP should reflect the variability in the combustion conditions. Comparisons of concentrations across runs even for the same stove type or wood type is therefore inappropriate. It is more appropriate to compare ratios relative to BEEP.

The average of the percent relative standard deviation (%RSD) of the ratios of the concentrations relative to BEEP by stove type ranged from 14 to 296%. Stove B had the most consistent ratios (lowest average %RSD of 92%) while the average %RSD for all species were similar for the other stoves (156 and 157%). The organic compounds with most consistent (across all three stoves) ratios were FLOR, PYRE, CHRY, BEBF, BAP and PERY all of which had %RSD of <100% for each stove. The inorganic species had average %RSD by stove type ranging from 45 to 288%. For the inorganics, stove B had the lowest average %RSD (116%) and again stoves A and C had similar average %RSD (180 and 195% respectively). The inorganic species therefore showed more variability across stove types. For the inorganic species, K, Cd and Pb had the most consistent ratios relative to BEEP.

3.3 SUMMARY OF RESULTS BY WOOD TYPE

Table 3-2A shows the mean concentrations of organic and inorganic species in emissions from the three types of wood - white birch, jackpine and maple. Table 3-2B summarizes the ratios of the organic and inorganic species to BEEP for each type of wood. Figures 3-3 and 3-4 show respectively, source profiles for three types of wood. In each case, the composition is expressed relative to BEEP for the organic and inorganic species. The average %RSD by wood type ranged from 15 to 283% with maple having the lowest average %RSD (125%) and birch and pine (168 and 144% respectively) having higher average %RSD. As was the case for the average %RSD by stove type, the compounds with the most consistent ratios (which were less than 100%) were FLOR, PYRE, CHRY, BEBF, BAP and PERY. For the inorganics, the %RSD were much higher with only Cd, Co, K, Mn and Pb having %RSD <200%.

TABLE 3-2

Average Concentrations Of Organic and Inorganic Species Produced By the Combustion Of Several Types Of Wood Regardless Of Stove Model

WOOD TYPE			WHITE BIRCH			JACKPINE			MAPLE		
	Symbol	Spec. #	Average Concentration		Standard Deviation	Average Concentration		Standard Deviation	Average Concentration		Standard Deviation
ORGANICS			(µg/m3)			(µg/m3)			(µg/m3)		
Fluorene	FLOR	222	149.1	±	130.3	239.1	±	353.9	272.5	±	162.7
Dibenzothiophene	DIBE	221	0.8	±	2.3	5.6	±	14.8	3.6	±	4.4
Phenanthrene	PHEN	231	199.6	±	229.2	220.8	±	360.8	229.4	±	96.7
Anthracene	ANTH	211	46.4	±	43.2	213.5	±	453.0	84.6	±	126.3
Acridine	ACRI	210				65.5	±	186.2	110.0	±	243.6
Carbizole	CARB	218	2.5	±	2.3	29.6	±	79.5	7.7	±	7.2
Fluoranthene	FLUO	223	215.5	±	115.4	338.3	±	471.4	266.9	±	128.0
Pyrene	PYRE	232	279.0	±	172.4	467.9	±	752.6	362.2	±	248.3
Retene	RETE	233	15.0	±	15.4	486.7	±	1070.3	8.7	±	13.6
Tetracosane	TETR	234	0.7	±	1.2	8.7	±	9.7	2.7	±	3.1
Pentacosane	TRIA	235	9.5	±	20.3	9.5	±	13.5	2.9	±	4.0
Chrysene	CHRY	219	107.6	±	66.6	324.0	±	596.1	268.7	±	215.1
1,2-Benzanthracene	BZA		152.0	±	94.4	418.6	±	765.7	300.8	±	324.2
Hexacosane	HEXA	225	4.1	±	4.7	24.3	±	49.9	7.0	±	7.2
Octacosane	OCTA	228	3.1	±	3.2	6.7	±	10.2	2.1	±	2.1
Benzo(b+k)Fluoranthene	BEBF	213	235.0	±	149.1	454.6	±	414.6	404.6	±	266.8
Nonacosane	NONA	227	2.2	±	2.8	7.0	±	9.4	2.0	±	2.0
Benzo(e)Pyrene	BEEP	215	68.1	±	41.9	137.1	±	216.8	203.3	±	284.7
Benzo(a)Pyrene	BAP	212	117.9	±	75.6	218.4	±	362.6	221.1	±	259.6
Perylene	PERY	230	26.7	±	14.6	39.1	±	56.0	58.2	±	60.1
Indeno(1,2,3-c,d)Pyrene	INDE	226	79.0	±	44.2	131.3	±	201.4	277.5	±	351.8
Dibenzo(a,h)Anthracene	DIAA	220	21.5	±	14.4	46.3	±	85.4	65.1	±	74.8
Benzo(ghi)Perylene	BEGP	216	102.2	±	53.9	114.7	±	175.4	366.9	±	483.8
INORGANICS											
Silver	Ag	47				0.4	±	0.6	0.1	±	0.2
Aluminum	Al	13	356.0	±	953.6	152.1	±	408.2	243.2	±	503.7
Bismuth	Bi	83									
Boron	B	5	467.3	±	1083.5	314.8	±	598.2	225.7	±	379.8
Barium	Ba	56	668.9	±	1794.9	360.9	±	727.7	408.6	±	844.1
Beryllium	Be	4	0.2	±	0.5	0.1	±	0.3	0.1	±	0.3
Cadmium	Cd	48	12.0	±	5.9	3.4	±	1.5	7.3	±	6.8
Calcium	Ca	20	72.3	±	189.7	81.8	±	200.0	51.0	±	120.7
Cobalt	Co	27	2.5	±	2.5	2.2	±	2.3	1.0	±	1.7
Chromium	Cr	24	0.4	±	0.4	0.4	±	0.3	0.6	±	0.6
Copper	Cu	29	3.3	±	2.6	1.5	±	1.3	2.6	±	3.2
Iron	Fe	26	11.9	±	12.3	4.6	±	6.7	7.9	±	6.8
Potassium	K	19	2537.1	±	2416.1	735.5	±	911.7	4240.2	±	1261.6
Manganese	Mn	25	13.6	±	8.5	15.4	±	11.0	4.7	±	2.5
Molybdenum	Mo	42									
Nickel	Ni	28	0.5	±	0.9	0.2	±	0.5	3.2	±	5.5
Lead	Pb	82	40.7	±	22.0	4.3	±	3.0	21.2	±	15.8
Tin	Sn	50									
Titanium	Ti	22									
Vanadium	V	23									
Zinc	Zn	30	1634.4	±	1884.1	310.3	±	572.1	555.0	±	759.8

TABLE 3-2B

Average Ratios Of Organic and Inorganic Species to BEEP Produced By the Combustion Of Several Types Of Wood Regardless Of Stove Model

WOOD TYPE			WHITE BIRCH			JACKPINE			MAPLE		
	Symbol	Spec. #	Average Ratio to BEEP		Standard Deviation	Average Ratio to BEEP		Standard Deviation	Average Ratio to BEEP		Standard Deviation
ORGANICS											
Fluorene	FLOR	222	2.51E+00	±	1.52E+00	2.22E+00	±	1.29E+00	2.76E+00	±	1.80E+00
Dibenzothiophene	DIBE	221	1.00E-02	±	2.69E-02	1.35E-02	±	2.57E-02	2.66E-02	±	2.29E-02
Phenanthrene	PHEN	231	3.83E+00	±	4.68E+00	2.39E+00	±	3.01E+00	5.34E+00	±	9.90E+00
Anthracene	ANTH	211	1.26E+00	±	1.53E+00	1.12E+00	±	1.60E+00	1.30E+00	±	1.72E+00
Acridine	ACRI	210				2.64E-01	±	4.94E-01	6.32E-01	±	1.46E+00
Carbizole	CARB	218	3.98E-02	±	2.61E-02	3.23E-01	±	7.18E-01	1.07E-01	±	1.24E-01
Fluoranthene	FLUO	223	4.38E+00	±	3.09E+00	3.99E+00	±	4.04E+00	4.27E+00	±	5.63E+00
Pyrene	PYRE	232	4.87E+00	±	2.37E+00	3.41E+00	±	2.54E+00	4.07E+00	±	3.77E+00
Retene	RETE	233	2.36E-01	±	2.25E-01	2.67E+00	±	3.20E+00	1.17E-01	±	2.86E-01
Tetracosane	TETR	234	7.65E-03	±	1.34E-02	6.79E-01	±	1.73E+00	4.27E-02	±	7.61E-02
Pentacosane	TRIA	235	1.13E-01	±	2.41E-01	7.55E-01	±	1.86E+00	1.14E-01	±	2.63E-01
Chrysene	CHRY	219	1.63E+00	±	3.28E-01	2.22E+00	±	9.72E-01	2.36E+00	±	2.08E+00
1,2-Benzanthracene	BZA		2.24E+00	±	3.40E-01	2.81E+00	±	1.40E+00	2.97E+00	±	3.28E+00
Hexacosane	HEXA	225	9.49E-02	±	1.59E-01	8.43E+00	±	2.39E+01	1.18E-01	±	1.55E-01
Octacosane	OCTA	228	5.98E-02	±	7.85E-02	3.63E-01	±	7.97E-01	7.47E-02	±	1.62E-01
Benzo(b+k)Fluoranthene	BEBF	213	3.64E+00	±	1.03E+00	5.26E+00	±	1.86E+00	4.50E+00	±	3.42E+00
Nonacosane	NONA	227	4.75E-02	±	7.78E-02	6.27E-01	±	1.42E+00	5.73E-02	±	1.07E-01
Benzo(e)Pyrene	BEEP	215	1.00E+00	±	0.00E+00	1.00E+00	±	0.00E+00	1.00E+00	±	0.00E+00
Benzo(a)Pyrene	BAP	212	1.68E+00	±	3.47E-01	1.42E+00	±	5.59E-01	1.72E+00	±	1.27E+00
Perylene	PERY	230	4.16E-01	±	7.37E-02	2.57E-01	±	1.39E-01	3.64E-01	±	1.29E-01
Indeno(1,2,3-c,d)Pyrene	INDE	226	1.27E+00	±	3.33E-01	1.37E+00	±	7.70E-01	2.26E+00	±	3.16E+00
Dibenzo(a,h)Anthracene	DIAA	220	3.02E-01	±	6.47E-02	4.52E-01	±	3.98E-01	5.03E-01	±	7.03E-01
Benzo(ghi)Perylene	BEGP	216	1.74E+00	±	6.85E-01	9.33E-01	±	4.13E-01	2.94E+00	±	4.72E+00
INORGANICS											
Silver	Ag	47				4.12E-02	±	9.45E-02	8.48E-04	±	2.28E-03
Aluminum	Al	13	4.39E+00	±	1.17E+01	1.48E+01	±	3.96E+01	8.50E-01	±	1.61E+00
Bismuth	Bi	83									
Boron	B	5	5.70E+00	±	1.33E+01	2.31E+01	±	5.72E+01	9.63E-01	±	1.27E+00
Barium	Ba	56	8.22E+00	±	2.20E+01	2.81E+01	±	7.10E+01	1.39E+00	±	2.37E+00
Beryllium	Be	4	2.06E-03	±	5.54E-03	9.51E-03	±	2.55E-02	1.49E-04	±	4.00E-04
Cadmium	Cd	48	2.86E-01	±	3.10E-01	3.60E-01	±	6.44E-01	5.29E-02	±	5.81E-02
Calcium	Ca	20	6.52E-01	±	1.70E+00	7.43E+00	±	1.96E+01	1.21E-01	±	2.05E-01
Cobalt	Co	27	2.84E-02	±	2.91E-02	5.22E-02	±	7.00E-02	6.06E-03	±	1.15E-02
Chromium	Cr	24	8.49E-03	±	1.29E-02	6.13E-02	±	1.25E-01	4.00E-03	±	5.42E-03
Copper	Cu	29	8.26E-02	±	1.32E-01	1.63E-01	±	3.35E-01	1.62E-02	±	9.61E-03
Iron	Fe	26	2.65E-01	±	4.02E-01	2.83E-01	±	6.59E-01	4.60E-02	±	5.60E-02
Potassium	K	19	3.73E+01	±	2.10E+01	3.80E+01	±	7.27E+01	4.05E+01	±	3.54E+01
Manganese	Mn	25	2.31E-01	±	1.59E-01	2.00E+00	±	3.69E+00	3.68E-02	±	2.81E-02
Molybdenum	Mo	42									
Nickel	Ni	28	2.03E-02	±	4.73E-02	1.96E-02	±	5.27E-02	1.03E-02	±	1.70E-02
Lead	Pb	82	1.09E+00	±	1.49E+00	4.04E-01	±	6.64E-01	1.65E-01	±	1.86E-01
Tin	Sn	50									
Titanium	Ti	22									
Vanadium	V	23									
Zinc	Zn	30	3.52E+01	±	5.33E+01	2.19E+01	±	5.37E+01	3.15E+00	±	5.58E+00

FIGURE 3-3

Organic Source Profiles (Relative to BeP) for Three Wood Types

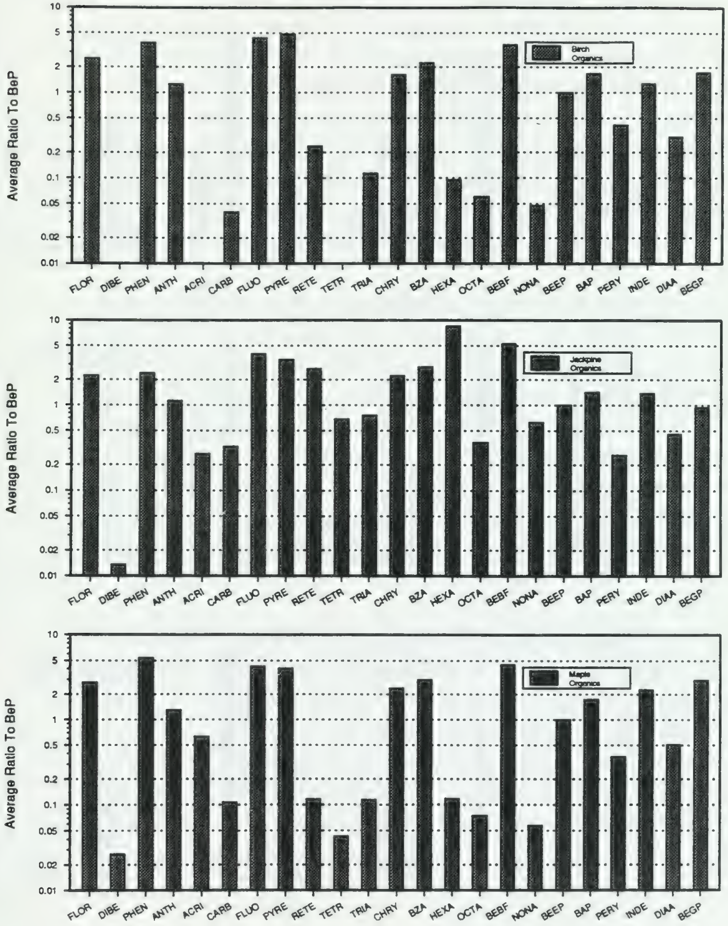
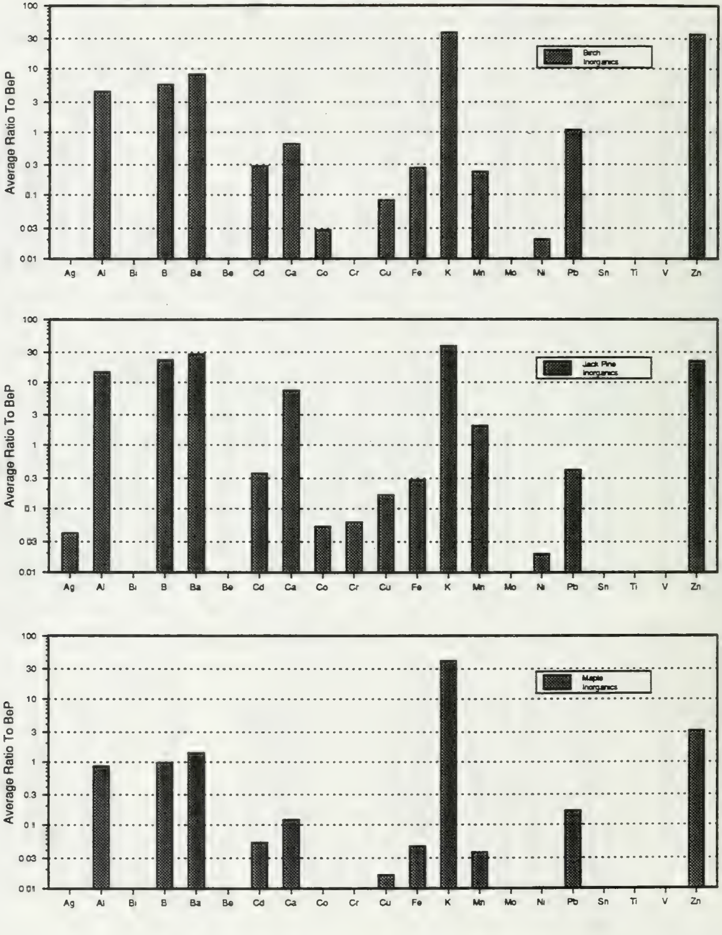


FIGURE 3-4

Inorganic Source Profiles (Relative to BeP) for Three Wood Types



3.4 SUMMARY OF ALL DATA

Table 3-3A lists the overall average concentrations and Table 3-3B the overall ratios relative to BEEP for all data without regard for wood and stove types. The %RSD in the ratios range from 37% to 444% with an average of 206%. The organic species had lower average %RSD (166%) than the inorganic species (average %RSD of 256%). The species with the most consistent ratios were PERY, BAP, BEBF, FLOR, CHRY, PYRE, BZA and FLUO all of which had average %RSD of <100% for organics and K, Co, Cd and Pb which had somewhat higher (<200%) average %RSD for the inorganics.

Figure 3-5 illustrates the source profiles for all data. Source profile data for wood stoves but for the particulate fraction alone, have been reported for residential wood stoves as listed in U.S. EPA source profiles (Core et al., 1989). The EPA profiles were obtained for the particle fraction alone (based on particles collected on filters) and thus comparisons with the profiles reported here (based on particle plus vapour phase catch) must bear these differences in mind. Table 3-4 lists the EPA and Concord (CEC) source profiles and Figures 3-6 and 3-7 show the profiles for this study (all data) and those from the EPA study. A more direct comparison of the profile obtained in this study with those in the U.S. EPA study is illustrated in Figures 3-8 and 3-9.

The uncertainty in the U.S. EPA source profiles (derived from data in Table 3-4) refer to uncertainties in the composition of the particle phase and ranges from 0 to 650% for inorganic species and 0 to 150% for organic species. For several species, especially inorganics, the reported average percent composition was zero but with non-zero uncertainties. Calculation of the average uncertainties in the ratios relative to BEEP for the EPA data are not possible since details of individual measurements were not available thus comparison of the uncertainties in the EPA profiles with those obtained in this study is not feasible.

TABLE 3-3A

Average Concentrations of Organic and Inorganic Species for the Entire Test Program Regardless of Wood Type or Stove Model

	Symbol	Spec. #	Average Concentration		Standard Deviation		Symbol	Spec. #	Average Concentration		Standard Deviation
ORGANICS			(µg/m3)			INORGANICS			(µg/m3)		
Fluorene	FLOR	222	223.8	±	223.6	Silver	Ag	47	0.2	±	0.4
Dibenzothiophene	DIBE	221	3.5	±	8.5	Aluminum	Al	13	250.4	±	594.0
Phenanthrene	PHEN	231	217.4	±	228.1	Bismuth	Bi	83			
Anthracene	ANTH	211	118.3	±	262.9	Boron	B	5	335.9	±	667.9
Acridine	ACRI	210	61.4	±	170.2	Barium	Ba	56	479.5	±	1085.8
Carbizole	CARB	218	13.8	±	44.4	Beryllium	Be	4	0.1	±	0.3
Fluoranthene	FLUO	223	276.5	±	271.7	Cadmium	Cd	48	7.6	±	5.9
Pyrene	PYRE	232	374.2	±	438.5	Calcium	Ca	20	68.3	±	153.9
Retene	RETE	233	177.9	±	619.2	Cobalt	Co	27	1.9	±	2.1
Tetracosane	TETR	234	4.2	±	6.5	Chromium	Cr	24	0.5	±	0.4
Pentacosane	TRIA	235	7.2	±	12.7	Copper	Cu	29	2.5	±	2.3
Chrysene	CHRY	219	239.7	±	352.6	Iron	Fe	26	8.1	±	8.5
1,2-Benzanthracene	BZA		297.4	±	460.2	Potassium	K	19	2504.3	±	2107.0
Hexacosane	HEXA	225	12.2	±	28.6	Manganese	Mn	25	11.2	±	8.7
Octacosane	OCTA	228	4.0	±	6.1	Molybdenum	Mo	42			
Benzo(b+k)Fluoranthene	BEBF	213	371.2	±	289.3	Nickel	Ni	28	1.3	±	3.2
Nonacosane	NONA	227	3.8	±	5.8	Lead	Pb	82	22.1	±	21.0
Benzo(e)Pyrene	BEEP	215	139.5	±	200.4	Tin	Sn	50			
Benzo(a)Pyrene	BAP	212	189.2	±	245.7	Titanium	Ti	22			
Perylene	PERY	230	42.1	±	46.4	Vanadium	V	23			
Indeno(1,2,3-c,d)Pyrene	INDE	226	166.8	±	234.7	Zinc	Zn	30	833.2	±	1235.7
Dibenzo(a,h)Anthracene	DIAA	220	45.4	±	63.8						
Benzo(ghi)Perylene	BEGP	216	199.2	±	304.8						

TABLE 3-3B

Average Ratios of Organic and Inorganic Species for the Entire Test Program Regardless of Wood Type or Stove Model

	Symbol	Spec. #	Average Ratio to BEEP		Standard Deviation		Symbol	Spec. #	Average Ratio to BEEP		Standard Deviation
ORGANICS			(µg/m3)			INORGANICS			(µg/m3)		
Fluorene	FLOR	222	2.49E+00	±	1.41E+00	Silver	Ag	47	1.40E-02	±	5.23E-02
Dibenzothiophene	DIBE	221	1.70E-02	±	2.37E-02	Aluminum	Al	13	6.67E+00	±	2.20E+01
Phenanthrene	PHEN	231	3.86E+00	±	6.10E+00	Bismuth	Bi	83			
Anthracene	ANTH	211	1.22E+00	±	1.46E+00	Boron	B	5	9.91E+00	±	3.16E+01
Acridine	ACRI	210	3.14E-01	±	8.68E-01	Barium	Ba	56	1.26E+01	±	3.97E+01
Carbizole	CARB	218	1.62E-01	±	4.09E-01	Beryllium	Be	4	3.91E-03	±	1.40E-02
Fluoranthene	FLUO	223	4.21E+00	±	3.99E+00	Cadmium	Cd	48	2.33E-01	±	3.91E-01
Pyrene	PYRE	232	4.08E+00	±	2.75E+00	Calcium	Ca	20	2.74E+00	±	1.06E+01
Retene	RETE	233	1.05E+00	±	2.13E+00	Cobalt	Co	27	2.89E-02	±	4.38E-02
Tetracosane	TETR	234	2.55E-01	±	9.83E-01	Chromium	Cr	24	2.46E-02	±	6.96E-02
Pentacosane	TRIA	235	3.38E-01	±	1.06E+00	Copper	Cu	29	8.74E-02	±	1.94E-01
Chrysene	CHRY	219	2.09E+00	±	1.28E+00	Iron	Fe	26	1.98E-01	±	4.10E-01
1,2-Benzanthracene	BZA		2.70E+00	±	1.94E+00	Potassium	K	19	3.86E+01	±	4.26E+01
Hexacosane	HEXA	225	3.02E+00	±	1.34E+01	Manganese	Mn	25	7.57E-01	±	2.10E+00
Octacosane	OCTA	228	1.71E-01	±	4.60E-01	Molybdenum	Mo	42			
Benzo(b+k)Fluoranthene	BEBF	213	4.51E+00	±	2.24E+00	Nickel	Ni	28	1.68E-02	±	3.74E-02
Nonacosane	NONA	227	2.54E-01	±	8.12E-01	Lead	Pb	82	5.53E-01	±	9.33E-01
Benzo(e)Pyrene	BEEP	215	1.00E+00			Tin	Sn	50			
Benzo(a)Pyrene	BAP	212	1.60E+00	±	7.72E-01	Titanium	Ti	22			
Perylene	PERY	230	3.42E-01	±	1.28E-01	Vanadium	V	23			
Indeno(1,2,3-c,d)Pyrene	INDE	226	1.65E+00	±	1.81E+00	Zinc	Zn	30	2.01E+01	±	4.11E+01
Dibenzo(a,h)Anthracene	DIAA	220	4.25E-01	±	4.41E-01						
Benzo(ghi)Perylene	BEGP	216	1.88E+00	±	2.70E+00						

TABLE 3-4

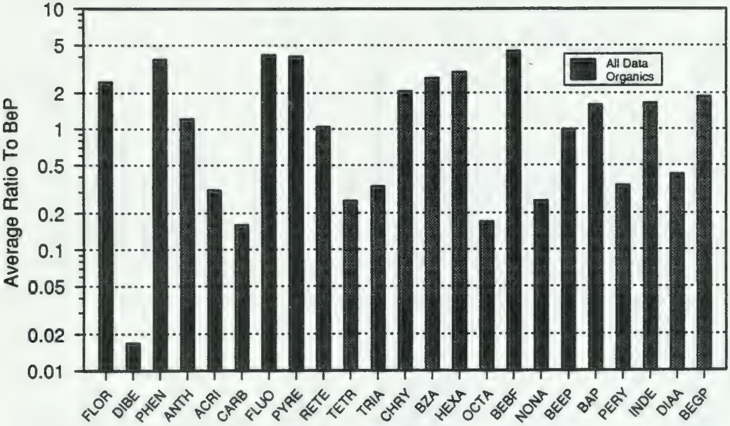
Comparison Of The Ratios Of Data To Benzo(e)Pyrene Concentrations For Profiles 105, 106 And CEC Experimental Data

Data Source				P105	P106	CEC	
Species Number	Species Name	Symbol	Average	Average Beep ratio	Average Beep Ratio	Average Beep Ratio	CAS
47	SILVER	Ag	0.000	0.00E+00	0.00E+00	1.40E-02	7440224
13	ALUMINUM	Al	0.005	1.67E+00	1.67E-01	6.67E+00	7429905
	BISMUTH	Bi					
	BORON	B				9.91E+00	
56	BARIUM	Ba	0.002	6.67E-01	6.67E-01	1.26E+01	7440393
	BERYLIUM	Be				3.91E-03	
48	CADMIUM	Cd	0.001	3.33E-01	0.00E+00	2.33E-01	7440439
20	CALCIUM	Ca	0.009	3.00E+00	1.67E+00	2.74E+00	7440702
27	COBALT	Co	0.000	0.00E+00	0.00E+00	2.89E-02	7440484
24	CHROMIUM	Cr	0.000	0.00E+00	0.00E+00	2.46E-02	7440473
29	COPPER	Cu	0.000	0.00E+00	0.00E+00	8.74E-02	7440508
26	IRON	Fe	0.000	0.00E+00	3.33E-01	1.98E-01	7439896
19	POTASSIUM	K	0.118	39.3	42.0	3.86E+01	7440097
25	MANGANESE	Mn	0.001	3.33E-01	1.67E-01	7.57E-01	7439965
42	MOLYBDENUM	Mo	0.000	0.00E+00	0.00E+00		7439987
28	NICKEL	Ni	0.000	0.00E+00	0.00E+00	1.68E-02	7440020
82	LEAD	Pb	0.000	0.00E+00	0.00E+00	5.53E-01	7439921
50	TIN	Sn	0.000	0.00E+00	0.00E+00		7440315
22	TITANIUM	Ti	0.000	0.00E+00	0.00E+00		7440326
23	VANADIUM	V	0.000	0.00E+00	0.00E+00		7440622
30	ZINC	Zn	0.021	7.00E+00	1.00E+00	2.01E+01	7440666

Data Source			P105	P106	CEC	
Species Number	Species Name	Symbol	Average Beep ratio	Average Beep Ratio	Average Beep Ratio	CAS
222	FLUORENE	FLOR	0.00E+00	1.67E-01	2.49E+00	86737
221	DIBENZOTHIOPHENE	DIBE	0.00E+00	0.00E+00	1.70E-02	132650
231	PHENANTHRENE	PHEN	6.67E-01	1.67E-01	3.86E+00	85018
211	ANTHRACENE	ANTH	3.33E-01	1.67E-01	1.22E+00	120127
210	ACRIDINE	ACRI	0.00E+00	0.00E+00	3.14E-01	
218	CARBAZOLE	CARB	0.00E+00	1.67E-01	1.62E-01	86748
223	FLUORANTHENE	FLUO	2.33E+00	1.50E+00	4.21E+00	206440
232	PYRENE	PYRE	2.67E+00	1.67E+00	4.08E+00	129000
233	RETENE	RETE	2.60E+01	2.10E+01	1.05E+00	
234	TETRACOSANE	TETR	3.33E-01	1.67E-01	2.55E-01	646311
229	PENTACOSANE	PENT	2.67E+00	1.67E-01	3.38E-01	629992
219	CHRYSENE	CHRY	3.00E+00	2.00E+00	2.09E+00	218019
	1,2-BENZANTHRACENE	BZA			2.70E+00	
225	HEXACOSANE	HEXA	6.67E-01	0.00E+00	3.02E+00	630013
228	OCTACOSANE	OCTA	0.00E+00	0.00E+00	1.71E-01	630024
213	BENZO(B+K)FLUORANTHENE	BEBF	2.33E+00	1.50E+00	4.51E+00	
227	NONACOSANE	NONA	0.00E+00	1.67E-01	2.54E-01	630035
215	BENZO(E)PYRENE	BEEP	1.00E+00	5.00E-01	1.00E+00	192972
212	BENZO(A)PYRENE	BAP	2.00E+00	1.00E+00	1.60E+00	50328
230	PERYLENE	PERY	6.67E-01	1.67E-01	3.42E-01	198550
226	INDENO(1,2,3-C,D)PYRENE	INDE	6.67E-01	0.00E+00	1.65E+00	193395
220	DIBENZ(A,H)ANTHRACENE	DIAA	0.00E+00	0.00E+00	4.25E-01	53703
216	BENZO(GHI)PERYLENE	BEGP	1.00E+00	3.33E-01	1.88E+00	191242

FIGURE 3-5

Organic and Inorganic Source Profiles (Relative to BeP) for All Data



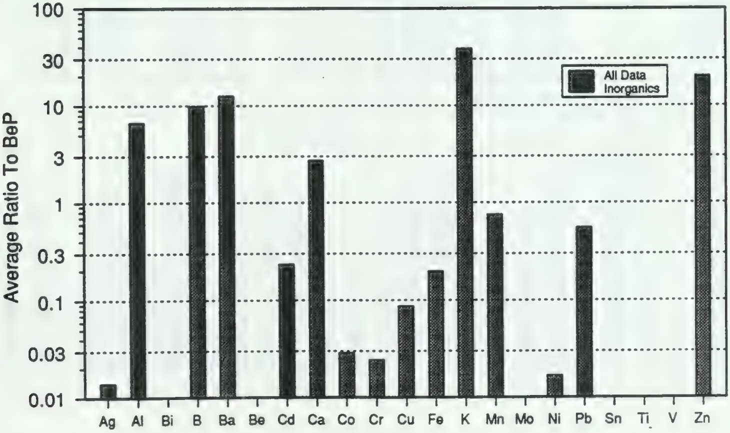


FIGURE 3-6

Comparison of Source Profiles for US EPA Profiles 105, 106 and CEC Experimental Data

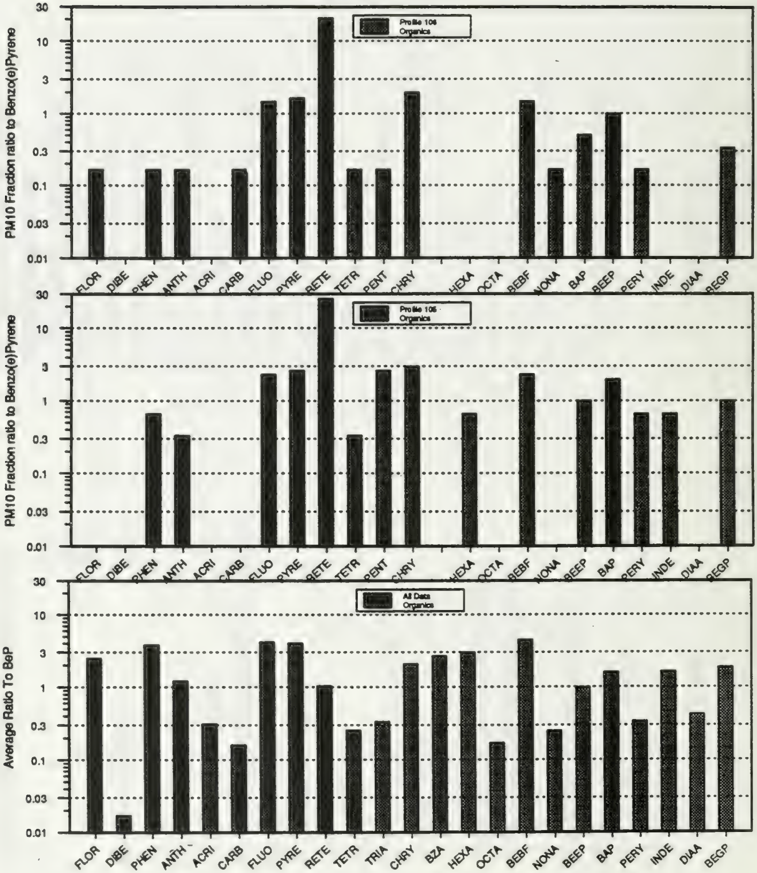


FIGURE 3-7

Comparison of Source Profiles for US EPA Profiles 105, 106 and CEC Experimental Data

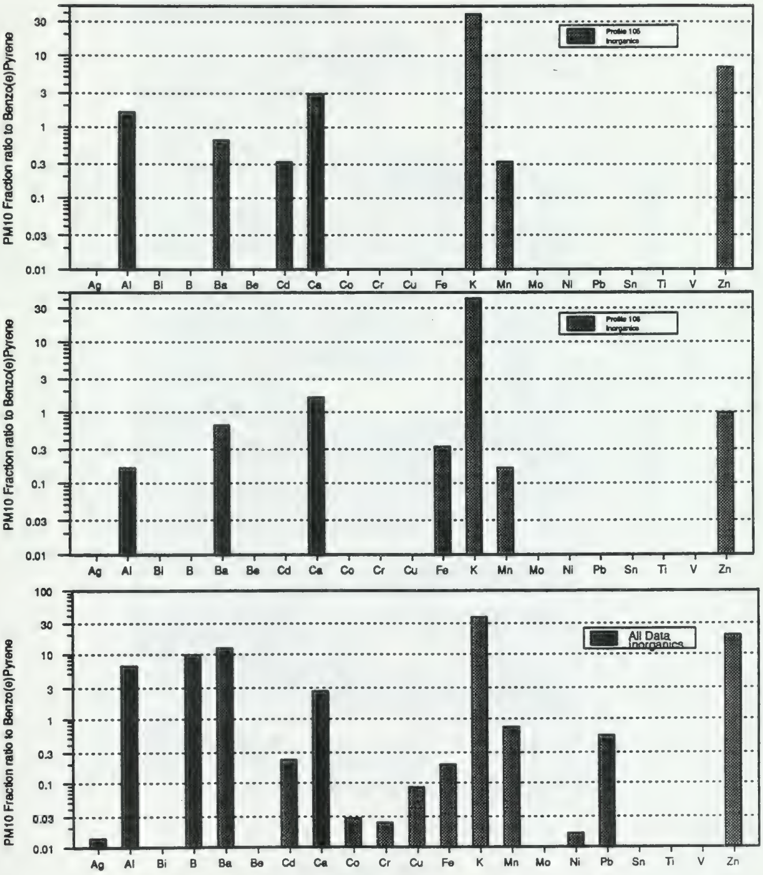


FIGURE 3-8

Comparison of Organic Source Profiles

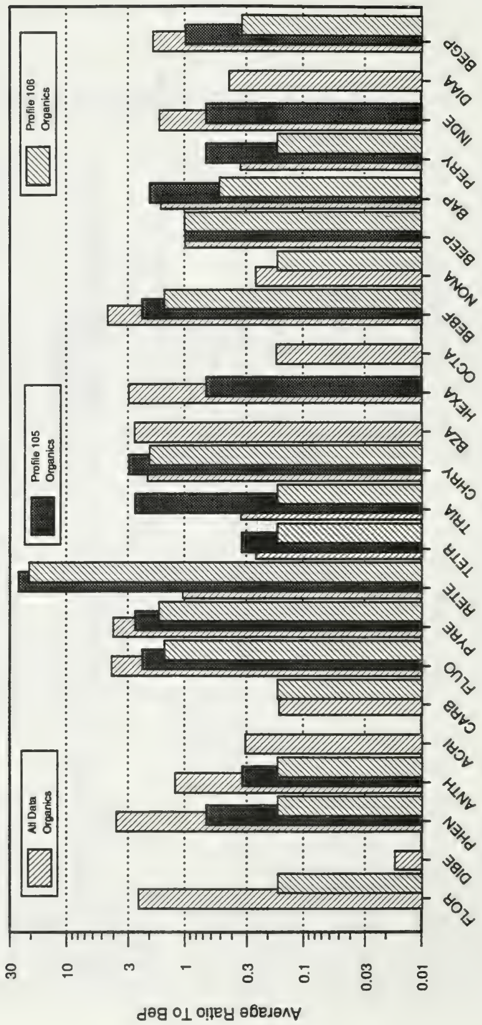
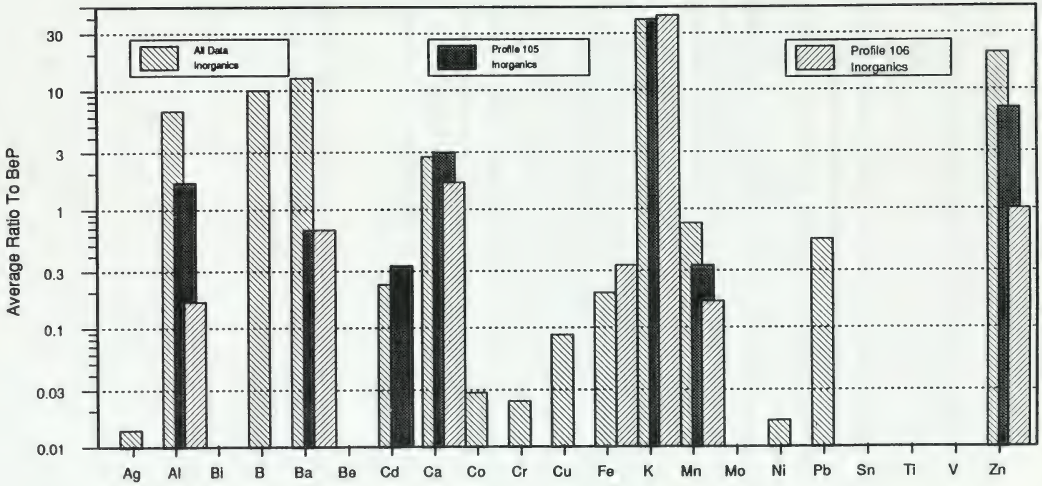


FIGURE 3-9

Comparison of Inorganic Source Profiles



The %RSD for the average concentrations obtained in this study averaged 163% and ranged from 78 to 348% for all species, 78 to 257% for inorganic species and 170 to 348% for inorganic species but the previously stated caveats regarding use of these %RSD must be noted. The range in uncertainties in stack sampling data is often greater than those measured here even in cases where the process conditions are presumable well controlled (e.g. in fuel oil combustion or coal combustion in a electric utility boiler. It should be noted also that notwithstanding the variability in the EPA source profiles, they have been used successfully in receptor modelling studies. The profiles obtained here should be acceptable for receptor modelling provided the sampling/analytical methodology is compatible with the profiles (i.e., combining the ambient particle and vapour phase catch) and using the (combined particle and vapour phase) profiles obtained in this study.

Examination of Figures 3-8 and 3-9 show differences between the two EPA profiles especially for PHEN, PERY, BEGP (different relative amounts) as well as for FLOR, CARB, HEXA and INDE (absence in one profile). The composite profile obtained in this study shows similarities for CARB, FLUO, PYRE, RETE, TETR, CHRY and BEBF. It should be stressed that comparisons of the EPA and Concord organic profiles should be made with extreme caution since the Concord composite profiles are based on particle and vapour phase sampling while EPA profiles were for particulate matter only. In the case of inorganic species, the feature common to the Concord composite and the EPA profiles is the high and consistent ratio for K. Consistent ratios also were obtained for Ca. Other species were variable across all three profiles.

The profiles for each wood type showed no major differences suggesting that wood types and stove types used have no dramatic influence on the source profiles for the components measured in this study.

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Daisey, J.M., Cheney, J.L., Lioy, P.J. (1986). Profile of Organic Particulate Emissions from Air Pollution Sources: Status and Needs for Receptor Source Apportionment Modelling. J. Air Pollution Control Association, Volume 36, Number 1, January 1986.

APPENDIX A

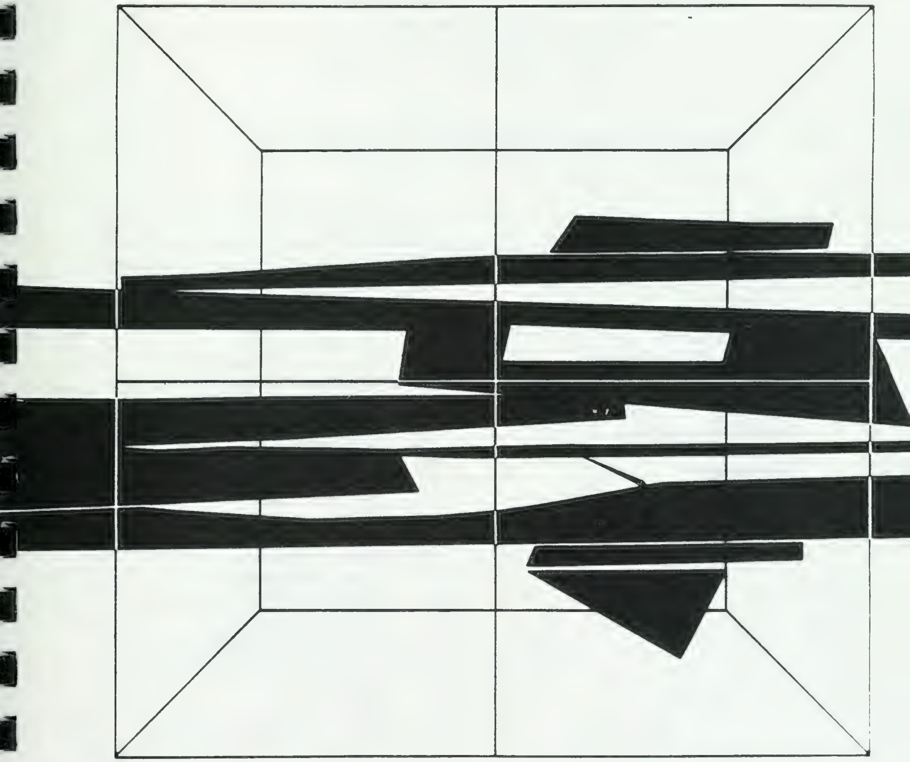
SAMPLING AND ANALYTICAL METHODS

APPENDIX A-1

REFERENCE METHOD FOR SOURCE TESTING: MEASUREMENT OF RELEASES OF SELECTED SEMI-VOLATILE ORGANIC COMPOUNDS FROM STATIONARY SOURCES

Reference Method for Source Testing: Measurement of Releases of Selected Semi-volatile Organic Compounds from Stationary Sources

Report EPS 1/RM/2
June 1989



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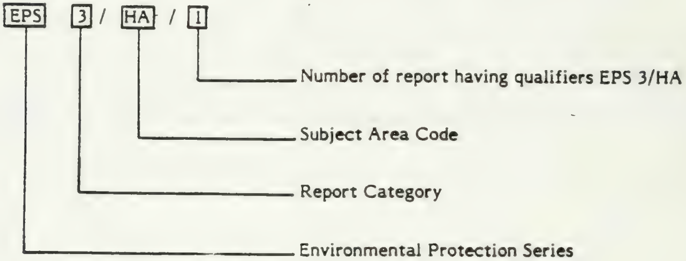
Sample Number:


EPS
3
HA
1
Number of report having qualifiers EPS 3/HA
Subject Area Code
Report Category
Environmental Protection Series

Categories

1	Regulations/Guidelines/Codes of Practice
2	Problem Assessments, and Control Options
3	Research and Technology Development
4	Literature Reviews
5	Surveys
6	Social, Economic and Environmental Impact Assessments
7	Surveillance
8	Policy Proposals & Statements
9	Manuals

Subject Areas

AG	Agriculture
AN	Anaerobic Technology
AP	Airborne Pollutants
AT	Aquatic Toxicity
CC	Commercial Chemicals
CE	Consumers and the Environment
CI	Chemical Industries
FA	Federal Activities
FP	Food Processing
HA	Hazardous Wastes
IC	Inorganic Chemicals
MA	Marine Pollution
MM	Mining & Ore Processing
NR	Northern and Rural Regions
PF	Paper and Fibres
PG	Power Generation
PN	Petroleum and Natural Gas
SF	Surface Finishing
SP	Oil & Chemical Spills
SRM	Standard Reference Methods
TS	Transportation Systems
TX	Textiles
UP	Urban Pollution
WP	Wood Protection/Preservation

New subject areas and codes are introduced as they become necessary. A list of EPS reports may be obtained from Environmental Protection Publications, Conservation and Protection, Environment Canada, Ottawa, Ontario, Canada, K1A 0H3.

REFERENCE METHOD FOR SOURCE TESTING: MEASUREMENT OF RELEASES OF SELECTED SEMI-VOLATILE ORGANIC COMPOUNDS FROM STATIONARY SOURCES

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Environment Canada

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FOREWORD

The Environment Canada Reference Method (RM) described in this document is used to measure the releases of selected semi-volatile organic compounds from stationary sources. This method is used in conjunction with those described in Environment Canada Report EPS 1-AP-74-1, "Standard Reference Method for Source Testing: Measurement of Emissions of Particulates from Stationary Sources", as amended. The complexity of method procedures warrants that personnel performing them be trained and experienced.

Application of this RM for compliance testing requires strict adherence to the method in all respects. Deviation from the method may invalidate the test results. Any changes in equipment, reagents, materials, procedures, or calculations from those specified in the RM must be approved in writing by Environment Canada prior to testing. If deviations are made without prior approval, the validities of the tests shall be determined by Environment Canada on a case-by-case basis.

NOTE: Mention of trade names or commercial products does not constitute endorsement for use by Environment Canada.

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1 APPLICABILITY

This Environment Canada Reference Method (RM) is applicable to the determination of emissions of polychlorinated dibenzo-*para*-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polychlorinated biphenyls (PCBs), and other semi-volatile organic compounds (SVOCs) from stationary sources. Semi-volatile organics are defined as compounds with boiling points greater than 100°C. The testing procedures in Method A,B,C,D and F, contained in Environment Canada Report EPS 1-AP-74-1, "Reference Methods for Source Testing: Measurement of Emissions of Particulates from Stationary Sources" (as amended), are to be used in conjunction with the SVOC method:

- Method A - Determination of Sampling Site and Traverse Points
- Method B - Determination of Stack Gas Velocity and Volumetric Flow Rates
- Method C - Determination of Molecular Weight by Gas Analysis
- Method D - Determination of Moisture Content
- Method F - Calibration Procedure for S-Type Pitot Tube, Dry Gas Meter and Orifice Meter.

2 PRINCIPLE

An integrated stack gas sample is isokinetically withdrawn from a number of traverse points along the stack cross section. Semi-volatile organic compounds associated with particulate matter are collected in the front-half components of the sampling train. Semi-volatile organic compounds not collected by the high efficiency glass or quartz fibre filter are adsorbed on a porous, polymeric resin, Amberlite XAD-2.

3 APPARATUS

3.1 Sampling Train (Figure 1)

The following equipment is required:

Nozzle: A button-hook type nozzle with a sharp, tapered leading edge. The nozzle is usually made of 316 stainless steel or Incoloy 825, but quartz or equivalent material may be used when high temperature or corrosive gases are encountered. The minimum inside diameter of the nozzle shall be 4.76 mm (3/16 inch).

Probe: A borosilicate or quartz glass liner, encased in a stainless steel tube with a heating and temperature indicating system capable of maintaining the exit gas temperature at 120 ± 14°C (248 ± 25°F), or at such a temperature necessary to prevent condensation. Where length or strength limitations preclude the use of a glass liner, a seamless tubing made from an inert material such as Teflon may be used. A water-cooled probe should be used when very hot gases which could damage the nozzle/probe assembly are encountered.

Pitot Tube: A calibrated S-type (Stausscheibe) pitot tube mounted on the probe assembly.

Stack Temperature Sensor: A thermocouple, or other suitable temperature sensor, mounted on the probe assembly, capable of measuring the stack temperature to within 1.5% of the minimum absolute stack temperature. When high temperature gases are encountered, appropriate shielding and aspiration should be provided for the thermocouple so that radiation effects are avoided.

Cyclone (Optional): A borosilicate miniature cyclone placed after the sampling probe and before the filter may be used to collect large particles. The cyclone prevents premature buildup of particulate matter on the filter medium and permits longer sampling periods. The cyclone is located inside the filter compartment and is kept at a temperature of 120 ± 14°C (248 ± 25°F).

Filter Holder: A borosilicate filter holder with an inert filter support. The filter support, which consists of a perforated disc, shall be constructed of Teflon to provide a seal against leakage at any point along the filter circumference. The filter holder is located inside the filter compartment and is maintained at a temperature of 120 ± 14°C (248 ± 25°F).

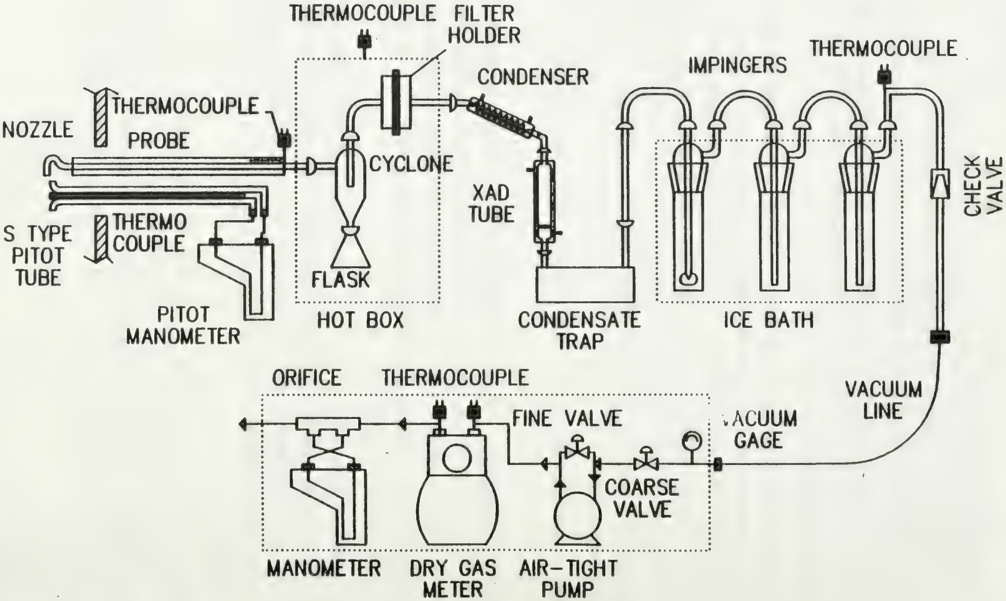


FIGURE 1 SEMI-VOLATILE ORGANICS SAMPLING TRAIN

Filter: A high-efficiency glass or quartz fibre filter, which contains no organic binders and is capable of at least 99.95% efficiency for 0.3 μm dioctyl phthalate smoke particles as determined by ASTM Method D2986-71.

Filter Compartment Heating System: A heating system capable of maintaining the temperature in the filter holder compartment at 120 ± 14°C (248 ± 25°F), or at such a temperature necessary to prevent blinding of the filter. A thermocouple or other temperature sensor must be able to read the filter compartment temperature to within 3°C (5°F).

Organic Sampling Module: This unit consists of a gas condensing coil, a sorbent trap and a condensate knockout trap. The condenser must be able to condition the stack gas leaving the back-half of the filter holder at a temperature below 20°C (68°F). The sorbent trap shall be sized to contain 30-40 g of porous polymeric resin, Amberlite XAD-2. The sorbent trap should contain a glass well to accommodate a thermocouple to permit monitoring of the temperature of the gas sample entering the sorbent. The organic sampling module shall be oriented so that the condensate flows vertically, downward through the XAD-2 resin, into the condensate trap. The condensate trap shall be suitably sized and designed to prevent bubbling and carryover of condensate into the impingers.

A peristaltic or submersible pump shall be used to circulate the coolant through the XAD-2 trap and condenser. Ice water from the impinger bath may be used as the coolant.

All components of the organic module (condenser, XAD-2 trap and condensate trap) shall be fabricated of borosilicate glass. These components are not available commercially, but they may be custom fabricated from available laboratory glassware.

Impingers: Three Greenburg-Smith impingers are connected in series. The second and third impingers are modified by replacing the tips and impaction plates of the standard design with a 13 mm (0.5 inch) inside diameter glass tube extending to within 13 mm (0.5 inch) from the bottom of the impinger. The first impinger has the standard tip and impaction plate. The impingers are contained in an ice bath during sampling. The first impinger shall contain a known volume of ethylene glycol. The second shall remain empty and the third shall contain a known weight of silica gel.

Vacuum Pump: A leakproof vacuum pump capable of maintaining an isokinetic sampling rate while continuously withdrawing a portion of the stack gases through the sampling train is used. The pump intake vacuum is measured to within 13 mm mercury (Hg) (0.5 inch Hg) by a vacuum gauge which is attached to the vacuum line connecting the pump to the last impinger outlet. The sample flow rate is controlled with both coarse-and fine-flow control valves.

Dry Gas Meter: A calibrated dry gas meter with inlet and outlet temperature sensors, or one that is temperature-compensated. The sensors must be capable of measuring the temperatures to within 3°C (5°F).

Orifice: A calibrated orifice connected to the outlet of the dry gas meter is required.

Differential Pressure Gauges: Differential pressure gauges such as an inclined manometer, or a device of equal sensitivity, which are capable of measuring the pitot tube velocity pressure and the pressure drop across the orifice to within 0.13 mm (0.005 inch) H_2O on the 0 to 25 mm (0 to 1 inch) H_2O scale, and readable to the nearest 1.3 mm (0.05 inch) H_2O for ΔP values greater than 25 mm H_2O.

A more sensitive device shall be required when ΔP values are less than 1.3 mm H_2O (0.05 inch H_2O).

Barometer: A mercury, aneroid, or other barometer capable of measuring atmospheric pressure to within 2.5 mm Hg (0.1 inch Hg). Alternatively, the atmospheric pressure provided by the local weather office may be used with an adjustment for the elevation of the sampling site. Deduct 2.5 mm Hg (0.1 inch Hg) per 30.5 m (100 feet) of elevation increase or add 2.5 mm Hg (0.1 inch Hg) per 30.5 m (100 feet) of elevation decrease.

3.2 Sample Preparation and Recovery

Probe Brush: A nylon bristle brush of a length and diameter suitable for cleaning the probe. The brushes shall be cleaned prior to field use and shall have stainless steel or Teflon extensions.

Wash Bottles: Teflon wash bottles are necessary to dispense the recovery solvents. Polyethylene wash bottles shall not be used as the organic solvents stored in the bottle may extract organic contaminants.

Sample Storage Containers: Wide-mouthed amber glass bottles to store the hexane and acetone rinse. The screw caps shall be lined with Teflon lid liners. Both the amber glass bottles and the Teflon lid liners shall be cleaned. The amber glass bottles shall be proofed prior to field use. Both 500-mL and 1000-mL capacity bottles are required.

Petri Dishes: Glass petri dishes to store and transport the filters. The glass petri dishes shall be cleaned before field use.

Teflon Lid Liners: Teflon sheet to line the inside of the screw caps. The lid liners shall be cleaned prior to field use.

Teflon Tape and Sleeves: Teflon tape is necessary to seal the circumference of the filter holder and the glass ball joints. Both 13-mm (1/2-inch) and 25-mm (1-inch) wide tape is required. The Teflon sleeves are used to seal the tapered impinger joints.

Glass Wool: Glass or quartz wool to plug the unfritted end of the sorbent trap. The wool shall be cleaned prior to field use.

Aluminum Foil: Aluminium foil to wrap the loaded filter and to cover the open ends of the train glassware. The foil shall be cleaned before use.

Miscellaneous: Miscellaneous glassware such as graduated cylinders, glass plugs and caps and funnels. This glassware shall be cleaned prior to field use. Tweezers (stainless steel or Teflon) and disposable plastic gloves are also required. Do not use latex gloves or gloves with powdered inside surfaces.

4 REAGENTS

All reagents used for organic testing shall be analyzed for organic contaminants prior to sampling. These reagents include the cleaning and rinsing solvents, High Purity Liquid Chromatography (HPLC) water, ethylene glycol and the XAD-2 resin.

Solvents: Solvents used for sampling shall be "Distilled-in-Glass" grade or "Pesticide Grade". These include methylene chloride (dichloromethane) hexane and acetone. Solvents may be screened by lot or batch number. Solvents from different batches will require a separate analysis.

HPLC Water: HPLC water for sample recovery is required.

Ethylene Glycol: Distilled-in-glass grade ethylene glycol shall be added to the first impinger. The glycol serves as a backup collection medium should organics break through the XAD-2 resin.

Amberlite XAD-2 Resin: Porous polymeric resin, XAD-2, is necessary to trap the gaseous semi-volatile organic compounds. The resin shall be cleaned and proofed before field use. Once cleaned, the XAD-2 should be stored in wide-mouthed amber glass jars with Teflon-lined caps and wrapped in aluminum foil. Resin not used within four weeks of preparation should be re-cleaned. The analytical procedure and acceptance criteria are described in the method specified in the Chemical Analysis Section. All XAD-2 traps (including the blank train and reagent blanks) must be loaded at the same time in a clean environment.

Ice: Crushed ice is required to maintain the impinger bath at a constant temperature.

Silica Gel: Indicating-type 6-16 mesh silica gel that has been dried at 180°C (356°F) for two hours is required.

5 PROCEDURES

5.1 Cleaning and Proofing

Before the field tests, all train glassware, amber storage bottles, Teflon lid liners, probe brushes, glass wool, petri dishes and aluminum foil must be cleaned as described in Table 1. The cleaning procedures also apply to miscellaneous items such as graduated cylinders, plugs and caps, funnels and tweezers. Other cleaning procedures are recognized, but the components must be proofed according to the procedures detailed in Table 1 and pass the acceptance criteria.

Caution: Handle all Solvents in a Well-Ventilated Area

The effectiveness of the cleaning procedures is verified by proofing selected components and reagents. Proofing ensures that the glassware, reagents and recovery solvents are free of pollutants prior to sampling. All components coming into contact with the stack gas or recovery samples must be cleaned, but it is not necessary to proof all the cleaned components. The proofing samples are analyzed as specified in Section 6, using High Resolution Gas Chromatography/Low Resolution Mass Spectography. The components and reagents that require proofing are as follows:

Train Glassware: Glassware cannot be re-used in the field with semi-volatile organic sampling. As a result, one complete set of pre-cleaned and proofed glassware must be allowed for each stack test. In addition, one complete set of glassware must also be allowed for the blank train. Assemble the complete sets of train glassware that will be needed and identify each set. Following the cleaning procedure described in Table 1, rinse each component from a train set three times each with hexane and acetone. Combine the rinses from each train into a pre-cleaned amber bottle with a pre-cleaned Teflon lid liner. Label the container. This sample constitutes the proof rinse for that train set. Repeat the above procedure for the other train sets and the blank train. Submit the proof rinses (one bottle per train) to the analytical lab for analysis.

Amber Glass Storage Bottles: Following the cleaning procedure, select three or four bottles from each box (48 bottles). Rinse these bottles three times each with hexane and acetone. Combine rinsings from each bottle in a pre-cleaned amber bottle with a pre-cleaned Teflon lid liner. Label the container and submit the proof rinse to the analytical laboratory. One proof rinse shall be submitted for each box of bottles.

TABLE I - CLEANING AND PROOFING PROCEDURES

Component	Cleaning	Proofing
Glassware including Teflon Filter Supports Probe Brushes* Petri dishes* Glass plugs* Glass caps* Graduated Cylinders* Funnels* Tweezers*	- Soak in RBS solution at 70°C for at least two hours. Scrub glassware with a brush. Discard RBS solution after each batch. - Wash twice in dishwasher with lab dish detergent. - Rinse with generous amounts of deionized water. - Rinse each component three times with methylene chloride. - Rinse each component three times with hexane. - Rinse each component three times with acetone. - Seal all open ends with pre-cleaned aluminum foil.	- Assemble as many complete sets of trains as glassware allows. - Identify each train set. - Wash each component from each train three times each with hexane and acetone. Combine all rinses from each train into a pre-cleaned amber bottle with pre-cleaned Teflon lid liner. **(Do not use methylene chloride)** - Submit one proof rinse for each train.
Amber glass bottles	- As above except that no scrubbing with brushing is required.	- Select 3-4 bottles from each box (48 bottles). Rinse three times each with hexane and acetone. Store rinsings from each bottle in a pre-cleaned amber bottle with pre-cleaned Teflon lid liner.
Teflon lid liners, Aluminum foil	- Cut to size - Soak at least three hours in methylene chloride. (Cover beaker, replace MC daily) - Rinse three times with hexane. - Rinse three times with acetone. (Note: Handle with tweezers only).	Proofing not required.
Glass wool	- Elute in a column with 500 mL hexane followed by 500 mL methylene chloride. Oven dry for 8 hours at 225°C.	Proofing not required.
Amberlite XAD-2	- Rinse with deionized water. - Sequential soxhlet extraction with methanol, methylene chloride and cyclohexane (20 hours each). Rinse with hexane (5 cycles). - Oven dry at 50°C for four hours in shallow trays lined with pre-cleaned aluminum foil. - Store in tightly-sealed, pre-cleaned glass bottles.	- Submit a 30 g aliquot from each drying tray for proofing analysis.

* Proofing not required for these components.

Notes:
- . all reagents distilled-in-glass grade
- . avoid latex gloves or gloves with powdered inside surface
- . all squeeze bottles made out of Teflon
- . handle all solvents in a well-ventilated area

Amberlite XAD-2 Resin: A 30 g aliquot of each cleaned batch is taken and analyzed. This procedure is described in greater detail in the analytical method specified in Section 6.

Hexane and Acetone: Submit a sample of each solvent in a pre-cleaned amber bottle with a pre-cleaned Teflon lid liner. Label each container, including the batch or lot number. Take an aliquot of each solvent to form a combined hexane/acetone proof rinse. Submit the combined rinse to the analytical lab for analysis.

Ethylene Glycol and HPLC Water: Submit a sample of each reagent in a pre-cleaned amber bottle with a pre-cleaned Teflon lid liner. Label each container and include the batch or lot number. Take an aliquot of each reagent to form a combined glycol/HPLC water proof rinse. Submit the combined rinse to the analytical lab for analysis.

5.2 Sample Collection

Preliminary: Select the sampling site and the minimum number of traverse points according to procedures described in Method A of Environment Canada Report EPS 1-AP-74-1, "Reference Method of Source Testing: Measurement of Emissions of Particulates from Stationary Sources" (as amended). Without previous knowledge of the stack variables, a preliminary test should be conducted to obtain the following data:

- velocity profile across the stack (Method B)
- stack temperature and pressure (Method B)
- stack gas molecular weight (Method C)
- stack gas moisture content (Method D)

Use the information to select the largest nozzle possible for isokinetic sampling. The recommended minimum nozzle size is 4.76 mm (3/16 inch) inside diameter. A nozzle size should be selected such that 3 to 4 m^3 (105.9 - 141.3 ft^3) of dry standard sample gas will be collected over an approximate four-hour sampling period.

Select a suitable probe length that will permit access to all the sampling points.

Select a total sampling time so that the sampling time per traverse point is equal to or greater than five minutes.

Sampling Train Preparation: Prepare the sampling train in a clean area to minimize contamination. Install the selected nozzle on the probe. Mark the probe to denote the location of each sampling point. Before preparing and assembling the train glassware, the components should be rinsed once each with hexane and acetone. Discard the rinses.

Carefully wrap the filter support with 25 mm (1-inch) Teflon tape along the circumference to provide a leak-free seal between both halves of the filter holder. Using a pair of tweezers, remove the filter from its petri dish, inspect for flaws and place on the perforated Teflon filter support. It is recommended that the filter assembly be "leak-checked" at 381 mm Hg (15 inches Hg) prior to assembly at the sampling site.

Add approximately 100 mL of ethylene glycol to the first impinger and about 200-300 g of silica gel to the third impinger. Weigh the condenser, XAD-2 trap, condensate trap and the three impingers to the nearest 0.5 g. Record each weight on the Moisture Analysis Data Sheet (Figure 2).

During the assembly of the train, the joints must be sealed by wrapping the ball joints with 13-mm (0.5-inch) Teflon tape. Do not use vacuum grease to seal the joints. The configuration of the glassware will determine to what extent the train can be assembled in the field lab. From train assembly to extraction of the stack sample, the open glassware joints must be sealed with pre-cleaned glass plugs or caps or aluminum foil at all times.

At the sampling site, set up the train as shown in Figure 1. Connect all temperature sensors and pitot lines. Adjust the filter compartment and probe heating systems to maintain a temperature of 120 ± 14°C (248 ± 25°F). Connect the cooling system. Do not add the water or ice until the pre-test leak check is completed.

Once the filter compartment and probe have reached the necessary temperatures, conduct a leak check on the sampling train. This is done by plugging the nozzle inlet and pulling a vacuum of 381 mm Hg (15 inches Hg). A leakage rate of less than 0.57 L/min (0.02 ft^3/min) or four percent of the estimated average sampling rate, whichever is less, is acceptable. Unacceptable leakage rates must be corrected. Record the leakage rate and the vacuum on the Organics Sampling Data Sheet (Figure 3). Place water and crushed ice in the impinger bath and turn on the coolant recirculating pump for the condenser coil and XAD-2 tube. During testing, the temperature of the XAD-2 must not exceed 20°C (68°F) for effective removal of the semi-volatile organic species. At all other times the XAD-2 must not be exposed to temperatures above 50°C (122°F) to avoid thermal degradation.

Sampling Train Operation: Verify the heating and cooling systems and check that the probe and pitot tube are properly aligned. Level and zero the manometer. Clean the

Plant ____________________

Location ____________________

Run Number ____________________

Date ____________________

Run Conducted By ____________________

Component	Contents	Weight (g)
Condenser	Empty	*Final* ________ *Initial* ________ *Gain* ________ *a*
Resin Trap	XAD-2	*Final* ________ *Initial* ________ *Gain* ________ *b*
Condensate Trap	Empty	*Final* ________ *Initial* ________ *Gain* ________ *c*
First Impinger	100 mL Ethylene Glycol	*Final* ________ *Initial* ________ *Gain* ________ *d*
Second Impinger	Empty	*Final* ________ *Initial* ________ *Gain* ________ *e*
Third Impinger	~200 g Silica Gel	*Final* ________ *Initial* ________ *Gain* ________ *f*

Weight of water collected = a + b + c + d + e + f

W_{H_2O} = ________ grams

FIGURE 2 MOISTURE ANALYSIS DATA SHEET

access port to avoid extraneous pick up of deposited material. To begin sampling, point the nozzle directly into the gas stream at the first traverse point. Block off the opening between the probe assembly and the access ports. With a nomograph or a programmable calculator, determine the orifice setting for isokinetic sampling. Record the initial dry gas meter reading. Immediately start the vacuum pump and adjust the sampling flow rate to isokinetic conditions. Sample for at least five minutes at each traverse point, the sampling time being the same for every point. Traverse the stack cross section and maintain isokinetic sampling (±10%) throughout the test. Record instrumentation readings on the Organics Sampling Data Sheet (Figure 3) every five minutes, or at regular intervals that are consistent with the sampling duration established for each point, whichever is less. To simplify recording in the field, values may be entered in units for which the sampling equipment is designed. These values may then be converted (if necessary) to the metric units specified in the equations where they are used. Readings must also be taken before and after a "leak-check" and when sampling is halted. Record all sampling interruptions.

During sampling, verify the heating and cooling systems. The temperature of the filter enclosure and probe must be 120 ± 14°C (248 ± 25°F). The XAD-2 temperature must be below 20°C. Verify the alignment of the probe and pitot tube to the gas stream. Check the level and zero of the manometer and adjust if necessary. Verify that the condensate volume is increasing as the run progresses. If the sampling system vacuum becomes so high that it is difficult to maintain isokinetic sampling the filter holder and/or sorbent tube must be replaced. If this occurs, a "leak-check" must be conducted before and after the replacement of the above components.

When it is necessary to halt sampling temporarily either to dismantle the sampling train during port change-over or to change a train component, turn off the pump and immediately withdraw the probe from the stack. Conduct a mandatory "leak-check" on the sampling train by plugging the nozzle and pulling a vacuum equal to or greater than the maximum value observed during sampling. Record the actual leakage rate. If the leakage rate exceeds 0.57 L/min (0.02 ft^3/min) or four percent of the sampling flowrate, whichever is less, consult Environment Canada regarding the validity of the test. If the leakage rate is acceptable, proceed with dismantling the sampling train or changing the train component. Before continuing the test, conduct a "leak-check" on the assembled train by following the pre-test "leak-check" procedures used during sampling train preparation.

Plant ________________

Location ________________

Run No. ________________

Date ________________

Stack Dia. ________________

Probe Length ________________

Probe Type ________________

Filter Media ________________

Leak Check 1) ________ CFM @ ______ "Hg

2) ________ CFM @ ______ "Hg

Barometric Pressure (P_{bar}) ________________

Nozzle Diameter (N_d) ________________

Pitot Coefficient (C_p) ________________

Moisture Content (B_{wo}) ________________

Dry Molecular Weight (M_d) ________________

Orifice Meter Coefficient (K_o) ________________

Dry Test Meter Coefficient (γ) ________________

Stack Static Pressure (Δp_s) ________________

Stack Test By ________________

Point No.	Time	Stack Gas Temp.	Velocity Pressure (Δp)	Orifice Pressure (ΔH)	Gas Meter Volume Reading	Gas Meter Temp.		Filter Box Temp.	Probe Temp.	XAD-2 Inlet Temp.	Pump Vacuum
						Inlet	Outlet				

FIGURE 3 ORGANICS SAMPLING DATA SHEET

When the test is completed, conduct a mandatory post-test check on the sampling train by plugging the nozzle and pulling a vacuum equal to or greater than the maximum value observed during sampling. Record the actual leakage rate which must be less than either 0.57 L/min (0.02 ft^3/min) or four percent of the sampling flow rate during the test, whichever is less. If the leakage rates are acceptable, proceed with the recovery of the samples.

When the test is finished, disconnect the probe and set it aside to cool. Seal both ends and take care not to lose any material in the probe. Disconnect the filter (and cyclone, if used) and seal both ends with pre-cleaned glass plugs or caps, or aluminum foil. Disconnect the XAD-2 and condenser. Seal both ends. Seal the ends of the impinger train. When transporting the sampling train components to the on-site lab, take care to minimize the possibility of sample loss or contamination. Samples must be recovered in a clean area.

Blank Train: One blank train must be submitted for every group of three sample trains. The blank train is handled in the same manner as the loaded train except that no stack gases are drawn through the train. However, a volume of ambient air equal to that drawn during the pre- and post-traverse "leak-checks" must be drawn through the blank train. Hence, on the day that the blank train will be submitted, it is necessary to record all volumes drawn into the sampling train during all "leak-checks". It is not necessary to heat the filter components of the blank train during sampling or to conduct "leak-checks" on the blank train. The sample recovery procedures for the loaded trains are also applicable to the blank train.

5.3 Sample Recovery

Nozzle, Probe, Cyclone and Front-Half of the Filter Holder: Wipe exterior surfaces of the nozzle and probe to remove excess particulate matter. Quantitatively recover the particulate matter and condensibles from the nozzle, probe, cyclone (if used), by-pass connector (if cyclone is not used) and the front-half of the filter holder by washing (with brush) these components with hexane and acetone. Wash and brush each component three times with hexane and acetone. Finally, rinse each component three times each with hexane and acetone. Store all rinses in a wide mouth amber glass bottle (pre-cleaned, with a pre-cleaned Teflon lid liner). Mark the liquid level on the outside of the bottle and label the container. Place the labelled container in a sealed clear plastic bag.

Note: The extension rod (stainless steel or Teflon) of the probe brush used to wash the probe liner shall be wiped with the recovery solvents prior to sample recovery.

Filter: Carefully remove the exposed filter from the filter holder and place on pre-cleaned aluminum foil with exposed side up. Carefully transfer any loose particulate matter or filter fibres adhering to the support of the filter holder with a dry nylon bristle brush or sharp blade. Fold the filter in half and crimp the foil to close the edges. Place in a pre-cleaned glass petri dish. Label the petri dish and seal with 25-mm (one inch) wide Teflon tape around the circumference. The petri dish may also be sealed with aluminum foil.

Back-half of Filter Holder and Condenser: Drain all the cooling water from the condenser and wipe the outside of the condenser to remove excess water. Weigh the condenser and record the weight on the Moisture Analysis Data Sheet. Soak each of these components five minutes each with hexane and acetone. Rinse each component three times each with hexane and acetone. Store the soak and rinses in a wide-mouth amber bottle (pre-cleaned, with a pre-cleaned Teflon lid liner). Mark the liquid level on the outside of the bottle and label the container. Place the labelled container in a sealed clear plastic bag.

XAD-2 Tube: Remove the aluminum foil on the tube and drain all the cooling water. Wipe the outside of the tube to remove excess moisture. Weigh the XAD-2 tube and record the weight on the Moisture Analysis Data Sheet. Seal both ends of the XAD-2 tube with pre-cleaned glass caps or plugs. Wrap the whole tube with aluminum foil and label the container.

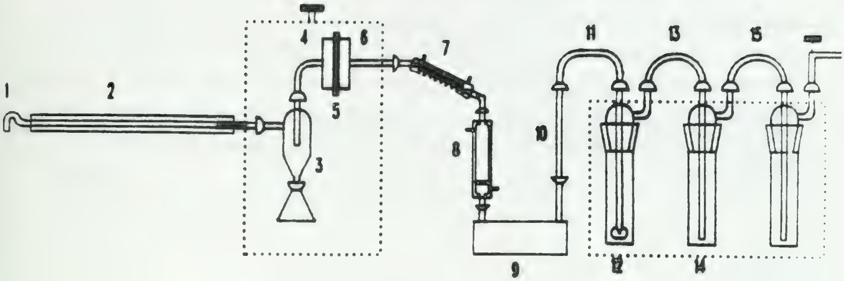
Condensate Trap and Ethylene Glycol Impinger: Wipe the outside of these components to remove excess moisture. Weigh each component and record the weights on the Moisture Analysis Data Sheet. Empty each container into a pre-cleaned amber glass bottle with a pre-cleaned Teflon lid liner. Rinse each component three times each with HPLC water into the same container. Mark the liquid level on the outside of the bottle and label the container. Place the labelled container in a sealed clear plastic bag.

Second and Third Impingers: Wipe the excess moisture from the outside of these impingers and weigh each impinger. Record each weight on the Moisture Analysis Data Sheet.

All Back-Half Glassware excluding XAD-2 Tube: Rinse each component including connectors three times each with hexane and acetone into a pre-cleaned glass amber bottle with a pre-cleaned Teflon lid liner. Mark the liquid level on the outside of the bottle and label the container. Place the labelled container in a sealed clear plastic bag. The sample recovery procedures for the front- and back-half components are illustrated in Figure 4.

Sample Handling: Following the recovery of the train components, all samples must be kept cool (approximately 4°C). They may be stored in a refrigerator or on ice in an insulated chest during field storage and transport to the analytical laboratory.

Before transporting the insulated chest, it is critical to ensure that the containers are well-packed to minimize sample loss. Many materials are available to protect the glass container against shock. Extra care should be taken when packing the samples.



Container or Sample	Component(s)	Recovery Procedure
1	1, 2, 3, 4	Wash and brush 3 times each with hexane (H) and acetone (A). Rinse 3 times each with H and A.
2	5	Remove carefully from holder. Place on pre-cleaned foil. Fold in half. Place in pre-cleaned glass petri dish.
3	6, 7	Soak 5 minutes each with H and A. Rinse 3 times each with H and A.
4	8	Cap ends and wrap in foil.
5	9, 12	Empty contents into container and rinse each 3 times with HPLC water.
6	6 to 15 except 8	Rinse 3 times each with H and A.

Mark liquid levels on all bottles.
All sample containers are pre-cleaned amber glass bottles with pre-cleaned Teflon lid liners.

FIGURE 4 SEMI-VOLATILE ORGANICS RECOVERY PROCEDURES

6 CHEMICAL ANALYSIS

The amount of PCBs, PCDDs and PCDFs in the test samples shall be determined by the Chemical Analysis procedures found in the Environment Canada document, "A Method for the Analysis of Polychlorinated Dibenzo-*para*-Dioxins (PCDDs), Polychlorinated Dibenzofurans (PCDFs), and Polychlorinated Biphenyls (PCBs) in samples from the Incineration of PCB Waste", Chemistry Division, Conservation and Protection, EPS-1/RM/3, 1989. The analytical results are to be used in Equation 10, Equation 11 and Figure 5.

7 CALCULATIONS

To simplify recording during a test, field data may be entered in the units for which the sampling equipment is designed. These values must be converted, if necessary, to the metric units specified in the applicable equations.

7.1 Equations (see Section 7.2 for Nomenclature)

Dry Gas Meter Volume: The total sample volume measured by the dry gas meter is corrected to reference temperature and pressure conditions (25°C and 101.3 kPa) using *Equation 1*. For a temperature-compensated dry gas meter $(T_m)_{avg}$ should be substituted by the temperature specified by the manufacturer.

Equation 1

$$(V_m)_{ref} = YV_m \frac{T_{ref}(P_{bar} + \Delta H_{avg})}{(T_m)_{avg}\, P_{ref}}$$

Volume of Water Vapour: The volume of water vapour in the sack gas sample expressed at reference conditions (25°C and 101.3Kpa) is calculated by using *Equation 2*.

Equation 2

$$(V_m)_{ref} = \frac{W_{H2O}\, 10^{-3}\, RT_{ref}}{M_{H_2O}\, P_{ref}}$$

Moisture Content: The volumetric fraction of water vapour in the stack gas expressed at reference conditions (25°C and 101.3 Kpa) is calculated using *Equation 3*.

Equation 3

$$B_{wo} = \frac{(V_w)_{ref}}{(V_w)_{ref} + (V_m)_{ref}}$$

For a saturated or suspersaturated stack, use a psychrometric chart to determine B_{wo}.

Absolute Stack Gas Pressure: The absolute stack gas pressure is calculated using *Equation 4.*

Equation 4

$$P_s = P_{bar} + \Delta p_s$$

Stack Gas Molecular Weight: The stack gas molecular weight on a wet basis is calculated using *Equation 5.*

Equation 5

$$M_s = M_d\,(1-B_{wo}) + 18\,B_{wo}$$

Stack Gas Velocity: The stack gas velocity measured at each traverse point is calculated using *Equation 6.*

Equation 6

$$U_s = 128.95\,C_p\left(\frac{\Delta p\,T_s}{P_s\,M_s}\right)^{1/2}$$

The average stack gas velocity $((U_s)_{avg})$ and stack gas temperature $((T_s)avg)$ for the test run are determined by averaging the velocities and temperatures respectively measured at the traverse points.

Volumetric Stack Gas Flow Rate: The average volumetric stack gas flow rate expressed on a dry basis and at reference conditions (25°C and 101.3 kPa) is calculated using *Equation 7.*

Equation 7

$$Q_s = 3600\,(U_s)_{avg}\,A_s\,(1-B_{wo})\quad\frac{T_{ref}\;P_s}{(T_s)_{avg}P_{ref}}$$

Isokinetic Variation: The isokinetic variation for each traverse points is calculated using *Equation 8.*

Equation 8

$$I = \frac{Y\,\dfrac{(V_m)_j}{t}\,\dfrac{1}{(1-B_{wo})}\,(P_{bar} + \Delta H)\,T_s}{4.71 \times 10^{-5}(N_d)^2\left(\dfrac{T_{mi} + T_{mo}}{2}\right)P_s\,U_s} \times 100$$

A test shall be considered valid when no more than 10% of the isokinetic values fall outside the range 90% to 110% and the average for all the traverse points I_{avg} falls within the range 90% to 110%.

Correction Factor: The pollutant concentrations expressed in this method must be corrected to a basis of 11% O_2. The correction factor to express concentrations at 11% O_2 is calculated using *Equation 9*.

Equation 9

$$f_{11\%\ O_2} = \frac{9.9}{20.9 - \%O_2}$$

Polychlorinated Biphenyl Emission Rates: The emission rate of polychlorinated biphenyls is calculated using *Equation 10*.

Equation 10

$$ER_{PCBs} = \frac{W_{PCBs}\,Q_s}{(V_m)_{ref}}$$

Concentrations of 2,3,7,8-TCDD Equivalent PCDDs and PCDFs: The concentration of 2,3,7,8-TCDD equivalent PCDDs and PCDFs corrected to 11% O_2 is calculated using *Equation 11*. The weight of 2,3,7,8-TCDD equivalent PCDDs and PCDFs is determined from Figure 5.

Equation 11

$$C_{2,3,7,8\text{-}T4CDD'} = \frac{W_{2,3,7,8\text{-}T4CDD'}\, f_{11\%\ O_2}}{(V_m)_{ref}}$$

7.2 Nomenclature

A_s - inside cross-sectional area of stack or duct, m^2

B_{wo} - volumetric fraction of water vapour in the stack gas, dimensionless

$C_{2,3,7,8\text{-}T4CDD'}$ - concentration of 2,3,7,8-T4CDD equivalent PCDDs and PCDFs on a dry basis at reference temperature and pressure conditions corrected to 11% O_2, ng/m^3 at 11% O_2

C_p - S-type pitot tube coefficient, dimensionless

ER_{PCBs} - emission rate of polychlorinated biphenyls, µg/h

ΔH_{avg} - average pressure drop across orifice meter, kPa

ΔH - pressure drop across orifice meter for each traverse point, kPa

I_{avg} - average isokineticity for the test, (%)

I - isokineticity i.e., the ratio of the sampling velocity through the nozzle to the velocity of the undisturbed gas stream at each traverse point, dimensionless, (%)

j - traverse point number, dimensionless

Md - molecular weight of stack gases on a dry basis, kg/kmol

M_s - molecular weight of stack gases on a wet basis, kg/kmol

M_{H_2O} - molecular weight of water, 18 kg/kmol

N_d - inside diameter of the sampling nozzle, mm

$f_{11\%O_2}$ - correction factor to convert concentrations at dry and reference temperature and presure conditions to 11% O2, dimensionless

$\%O_2$ - concentration of oxygen in the stack gas (dry basis), % by volume

P_s - absolute stack gas pressure, kPa

P_{bar} - barometric pressure at the sampling site, kPa

Δp - pitot-tube velocity pressure reading at each traverse point, kPa

P_{ref} - reference pressure, 101.3 kPa

Δp_s - static pressure of the stack gas, kPa

Q_s - volumetric stack gas flow rate on a dry basis at reference temperature and reference pressure conditions, m^3/h

R - universal gas constant, 8.31 kPa $m^3(kmol \cdot K)^{-1}$

t - sampling duration for each traverse point, min

$(T_s)_{avg}$ - average of the absolute stack gas temperatures, K

T_s - absolute stack gas temperature at each traverse point, K

$(T_m)_{avg}$ - average of the absolute dry gas meter temperatures, K

T_{mi} - absolute temperature at the dry gas meter inlet for each traverse point, K

T_{mo} - absolute temperature at the dry gas meter outlet for each traverse point, K

T_{ref} - reference temperature, 298 K

$(U_s)_{avg}$ - average stack gas velocity, m/s

U_s - stack gas velocity measured at each traverse point, m/s

V_m - volume of stack gas sample at dry gas meter conditions, m^3

$(V_m)_j$ - volume of stack gas sample at dry gas meter conditions for each traverse point, m^3

$(V_m)_{ref}$ - volume of stack gas sample at reference conditions, m^3

CONGENER	TRAIN CATCH		TOXICITY FACTOR		EQUIVALENT TRAIN CATCH
PCDDs					
1. 2,3,7,8-T4CDD		X	1.0	=	
2. 1,2,3,7,8-P5CDD		X	0.5	=	
3. 1,2,3,4,7,8-H6CDD		X	0.1	=	
4. 1,2,3,6,7,8-H6CDD		X	0.1	=	
5. 1,2,3,7,8,9-H6CDD		X	0.1	=	
6. 1,2,3,4,6,7,8-H7CDD		X	0.01	=	
7. O8CDD		X	0.001	=	
PCDFs					
8. 2,3,7,8-T4CDF		X	0.1	=	
9. 1,2,3,7,8-P5CDF		X	0.01	=	
10. 2,3,4,7,8-P5CDF		X	0.5	=	
11. 1,2,3,4,7,8-H6CDF		X	0.1	=	
12. 1,2,3,6,7,8-H6CDF		X	0.1	=	
13. 1,2,3,7,8,9-H6CDF		X	0.1	=	
14. 2,3,4,6,7,8-H6CDF		X	0.1	=	
15. 1,2,3,4,6,7,8-H7CDF		X	0.01	=	
16. 2,3,4,6,7,8,9-H7CDF		X	0.01	=	
17. O8CDF		X	0.001	=	

$W_{2,3,7,8\text{-T4CDD}'}$ = 2,3,7,8-T4CDD Equivalent PCDDs and PCDFs (add 1 to 17)

FIGURE 5 CALCULATION OF 2,3,7,8-T4CDD EQUIVALENT PCDDs AND PCDFs

$(V_w)\mathrm{ref}$ - volume of water vapour in the stack gas sample at reference conditions, m^3

W_{H_2O} - weight of water vapour condensed in the impingers, g

W_{PCBs} - weight of polychlorinated biphenyls collected in the semi-volatile organics sampling train, mg

$W_{2,3,7,8\text{-}T4CDD'}$ - weight of 2,3,7,8-TCDD equivalent PCDDs and PCDFs collected in the semi-volatile organics sampling train, ng

Y - dry gas meter calibration factor (ratio of the wet test meter volume to the dry test meter volume) dimensionless

128.95 - proportionality constant $(m/s)(K^{-1}\cdot kg/kmol)^{1/2}$

REFERENCES

1. Environment Canada, "Standard Reference Method for Source Testing: Measurement of Emissions of Particulates from Stationary Sources", Report EPS 1-AP-74-1 February 1974 (as amended).

2. Bursey, J., M. Hartman, J. Homolya, R. McAllister, J. McGaughey, D. Wagoner. "Laboratory and Field Evaluation of the Semi-VOST Method, Volume II: Appendices", EPA/600/4-85/0756 NTIS No. PB 86-123569 (November 1985).

APPENDIX A-2

METHODOLOGY FOR PAH AND ALIPHATIC HYDROCARBON EXTRACTION

METHODOLOGY FOR PAH AND ALIPHATIC HYDROCARBON EXTRACTION

I. GENERAL

There were 24 target compounds for GC/MSD analysis. Table I presents these chemicals. In addition to 24 target compounds , d10-Fluorenthene and d12-benzo(ghi) perylene were used as the performance standards to monitor GC/MSD and operator variability. d12-chrysene and d10-Phenanthrene were used as the surrogate standards to evaluate the extraction efficiency. The concentrations of the performance standards were the same in the samples and in the standards while the surrogate standards are spiked into the samples with the known amounts prior to the extractions.

TABLE I.

PAHs and other HCs for GC/MSD analysis.

1 Fluorene
2 Carbazole
3 d10-Phenantrene (surrogate)
4 Phenanthrene
5 Anthracene
6 Acridine
7 Dibenzothiophene
8 d10-fluorenthene (performance)
9 Fluorenthene
10 Pyrene
11 d12- Chrysene (surrogate)
12 chrysene
13 1,2-Benzanthracene
14 Retene
15 Benzo(b)fluoranthene
16 Benzo(k)fluoranthene
17 Benzo(e)pyrene
18 Benzo(a)pyrene
19 Perylene
20 Indeno(1,2,3-c,d)pyrene
21 d12-Benzo(ghi)perylene (performance)
22 Benzo(ghi) perylene
23 Dibenzo(a,h)anthracene
24 Tetracosane
25 Pentacosane
26 Hexacosane
27 Octacosane
28 Nonacosane

The concentrations of the performance standards in the samples and in the standards were about 5 ng/μL each while the spiked amounts of the surrogate standard in the samples was about 15000 ng/sample. (The concentration of the stock solution of the performance standards was 1000 ng/μ, and 5 μL of this stock was spiked into

1 mL sample or standard to have the concentration of 5 ng/µL. The concentration of the stock solution of the surrogate is 300 ng/µL; 50 µL of this stock is spiked into the sample prior to the extraction to have 15000 ng/sample.)

Instructions for soxhlet extraction, solvent extraction and clean-up procedures are indicated below.

II. SOXHLET EXTRACTION

- Assemble the Soxhlet apparatus as described in FIG.1.
- Charge the soxhlet with 250 mL of CH_2Cl_2 (EPA method), reflux for 2 hours and discard CH_2Cl_2.
- Place XAD-2 (or filter) into the thimble. Spike 15000 ng of d12-chrysene and 15000 ng of d-10 phenanthrene into the XAD-2.
- Add 300 mL of CH_2Cl_2 into the soxhlet, reflux the soxhlet system for 18 hours at the rate of at least 3 cycles/hour.
- Combine CH_2Cl_2 with the solvent used for cleanning sampling system (TS1 with CH_2Cl_2 extracted from filter. TS4 with CH_2Cl_2 extracted from XAD-2).
- Dry the combined solution by passing it through a drying column containing 10 grams of anhydrous sodium sulfate.
- Wash the extractor flask sodium sulfate with 100-125 mL CH_2Cl_2 to complete the quantitative transfer.

III. SOLVENT EXTRACTION

- Transfer the aqueous samples (from 3 impingers) to 2 L separatory funnels.
- Spike 15000 ng of d10-phenanthrene and 15000 ng of d-10 chrysene into the funnel
- Rinse the container 3 times with DI water (100 mL each) and the rinsing water is added to the funnel.
- Extract 3 times with 100, 100 50 mL of methylene chloride.
- Dry CH_2Cl_2 by passing through a sodium sulfate column as described above.
- Combine this methylene chloride with CH_2Cl_2 extracted from XAD-2 and solvent used for cleaning zone 2.
- Blow down the combined solvent to 3 mL.

IV. CLEANUP PROCEDURE

Before the clean up of the sample , the solvent exchange has to be performed.

- Add 15 mL cyclohexane to the blown down solvent (3 mL) and blow down to 3 mL.

- Pack 10 gr of activated silicagel in methylene chloride slurry to the column (See Figure 2)
- Add 1 gr of anhydrous sodium sulfate to the top of silica gel.
- Pre wash the column with 40 mL of CH_2Cl_2.
- Pre-elute the column with 40 mL of pentane.
- Transfer the concentrated sample extract (about 3 mL) to the column by pasteur pipette.
- Rinse sample flask 3 times with 1 mL of cyclohexane
- Elute the column with 50 mL of pentane. This pentane contains aliphatic hydrocarbon (AHC).
- Elute the column with 100 mL CH_2Cl_2/pentane (4+6)(v/v). This solvents contains PAHs.
- Combine pentane and mix pentane and CH_2Cl_2
- Blow down to about 3 mL
- Add 10 mL of toluene and blow down to final volume of 3 mL
- Transfer 1 mL of sample to the auto sampler vial and spike 5 µL of performance standards.
- Sample is ready for GC/MSD analysis.

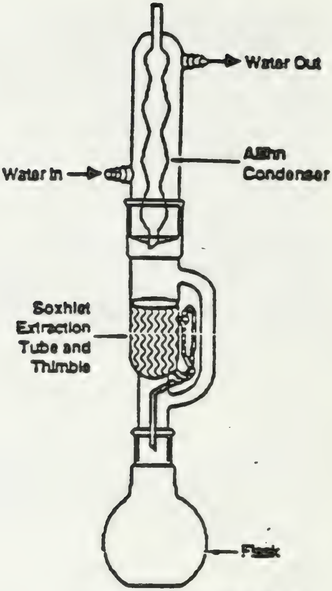
References:

(1) "Determination of benzo(a)pyrene and other polynuclear aromatic hydrocarbon in ambient air using gas chromatographic and high performance liquid chromagraphic analysis". Compendium method TO-13, US EPA May, 1988.

(2) Method 610: Polynuclear aromatic hydrocarbon. US EPA October, 1984.

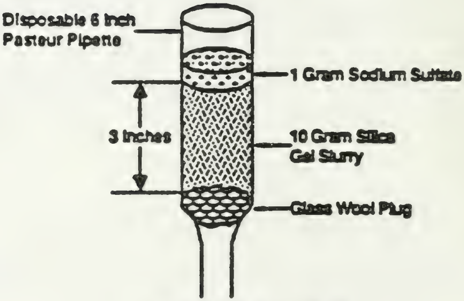
(3) "Methodology for organic analysis NITEP/ Quebec Combustion tests". Analysis Service Division, Technology Development @ Technical Service Branch. River road Environmental Technology Center. Ottawa, Ontario,K1A OH3, September, 1987.

FIGURE I.



Soxhlet Extraction Apparatus with Allihn Condenser

FIGURE II.



Silica Gel Clean-up Column

APPENDIX A-3

ANALYTICAL PROCEDURE FOR PAH AND AHC ANALYSIS

ANALYTICAL PROCEDURE FOR PAH AND AHC ANALYSIS

Preparation of Standard

PAH and AHC stock solutions were prepared separately in 25 mL volumetric flasks. From these stock solutions, mixtures of 100 ng/μL of each PAH and AHC in toluene were made in 50 mL volumetric flasks by spiking known amounts of each PAH and AHC using a 0.5 mL syringe (microliter #750, Hamilton Co., Reno. Nevada). A series of PAH and AHC standards in toluene were prepared by dilution from the 100 ng/μL solution above. Two stock solutions of performance standards (d10-fluoranthene and d12-benzo(ghi)perylene) in toluene were prepared separately with concentrations of 1000 ng/μL each. These solutions were used to spike the PAH standards and final extracts of sample to give a constant concentration of 5 ng/μL regardless of standards of PAH and AHC. The performance standards served as time reference compounds, whose elution times were used to adjust for slight changes in retention time of the compounds of interest during the GC analysis. This increased confidence level of analytical results. Stock solutions of d10-phenanthrene and d12-chrysene in toluene were prepared separately with concentration of 300 ng/μL each. These two stock solutions of deuterated compounds were used to spike samples as internal standards before the extraction processes carried out to evaluate the recovery efficiency. Table 1 lists the amounts of each compound used in the preparation of the standards of PAH and AHC.

Analytical Instrumentations

All analyses for PAH and AHC compounds were performed on a gas chromatograph/mass selective detector system (GC/MSD) operating in selective ion monitoring (SIM) mode. Separation of PAH and AHC compounds was achieved with an HP5890 GC Series II (Hewlett Packard Canada, Mississauga, Ontario) equipped with a J&W DB-5 fused silica capillary column (30 m x 0.25 mm x 0.25 μm thickness, J&W Scientific Inc., Folsom, CA.). The chromatographic conditions used for all analyses were as follows:

- initial temperature: 100 °C
- initial hold time: 1 minutes
- initial ramp: 10 °C/min to 110 °C
- second ramp: 15 °C/min to 300 °C
- injector temperature: 270 °C
- septum purge initiation: 1 minutes

All injections were 2 µL in volume and were delivered by an HP Automatic Liquid Sampler (ALS, model 18593B, HP 7673).

Helium (ultra high purity, supplied by Medigas, Toronto, Ontario) was used as carrier gas with a flow rate of 1 mL/min. The GC column was introduced into the ion chamber of the HP 5971A Mass Selective Detector (MSD) through a GC/MSD interface maintained at 310 °C. The ion source was a 70 eV electron impact ion source and the electron multiplier was set at 2300 volts. Daily tuning of the MSD was performed using the built-in perfluorotributylamine (PFTBA) source and autotune procedure. The data acquisition was controlled by the HP G1030A MS ChemStation (DOS series) equipped with an HP Vectra 386/25 computer and an HP Laserjet III printer. The MS ChemStation was operated with a graphical user interface software which operated using Microsoft Windows 3.0. The software controlled MSD, GC, and ALS operation and acquired mass spectral data. The software also allowed custom report generation.

Analysis and Calibration

From the mass spectrum of the compounds of interest, the target ion (usually the molecular ion) and two qualifier ions (the two most reprentative ions) were selected. The target ions were used for quantitation while the other two ions for confirmation of the compounds. To be qualified for a PAH or AHC compound, these two ions must be present in correct proportions relative to the target ion. However, due to a small variation in relative ion abundance of the mass spectrum with concentrations, a window of ±15% for each qualifier relative to target ion was established. Table 2 lists retention times and ions used for quantitation and confirmation of the target compounds of PAHs and AHCs.

The external standard procedure was used to quantify the target compounds. Calibration curves for individual compounds (Figures 1-26) were established using a linear regression technique. To minimize the error due to the changes in MSD sensitivity, a complete set of calibration standards was analysed in each analysis series. Based on signal/noise ration of 3, the method detection limit for the target compounds was less than 0.1 ng/µL or was less than 0.3 µg/sample.

Extraction Efficiency

Before the extraction of real samples, a series of recovery tests were performed with spiked samples to evaluate the performance of the extraction procedure (attached). Three sorbents (XAD-2, water, filter) were spiked with 15000 ng each target compound in duplicate. Two blanks (not spiked) for each sorbent were also prepared. The samples were then extracted following the methodology for PAH and AHC extraction developed previously (see attached). Table 3 presents extraction efficiencies of the target compounds. In general the recovery efficiencies for target compounds were better than 70 %. Recovery of acridine was very low (10-16%) , which may be attributed to the polarity of acridine.

TABLE 1
Preparation of standards for PAH's and AHC's

Compounds	Individual stock in 25 mL (ng/ul)	Volume transferred to 50 mL to have 100 ng/μL (mL)	stock2 (ng/ul)	from stock 2 std–1 (1/2) (ng/ul)	std–2 (1/4) (ng/ul)	std–3 (1/10) (ng/ul)	from std–3 std–4 (0.5/10) (ng/ul)	std–5 (1/10) (ng/ul)	std–6 (0.5/10) (ng/ul)	std–7 (0.1/10) (ng/ul)
1 FLUORENE	7615	0.66	100	50	25	10	5	1	0.5	0.1
2 DIBENZOTHIOPHENE	5270	0.95	100	50	25	10	5	1	0.5	0.1
3 d10–PHENANTHRENE	4018	1.24	100	50	25	10	5	1	0.5	0.1
4 PHENANTHRENE	5790	0.86	100	50	25	10	5	1	0.5	0.1
5 ANTHRACENE	4318	1.16	100	50	25	10	5	1	0.5	0.1
6 ACRIDINE	4060	1.23	100	50	25	10	5	1	0.5	0.1
7 CARBAZOLE	5978	0.84	100	50	25	10	5	1	0.5	0.1
8 d10–FLUORANTHENE	4843			5	5	5	5	5	5	5
9 FLUORANTHENE	7520	0.66	100	50	25	10	5	1	0.5	0.1
10 PYRENE	8180	0.61	100	50	25	10	5	1	0.5	0.1
11 RETENE	4198	1.19	100	50	25	10	5	1	0.5	0.1
12 TETRACOSANE	5855	0.85	100	50	25	10	5	1	0.5	0.1
13 PENTACOSANE	3415	1.46	100	50	25	10	5	1	0.5	0.1
14 CHRYSENE	2730	1.83	100	50	25	10	5	1	0.5	0.1
15 d12–CHRYSENE	2725	1.83	100	50	25	10	5	1	0.5	0.1
16 1,2–BENZANTHRACENE	4198	1.19	100	50	25	10	5	1	0.5	0.1
17 HEXACOSANE	2305	2.17	100	50	25	10	5	1	0.5	0.1
18 OCTACOSANE	3370	1.48	100	50	25	10	5	1	0.5	0.1
19 BENZO(b+k)FLUORANTHENE	6346	3.17	200	100	50	20	10	2	1	0.2
20 NONACOSANE	3580	1.40	100	50	25	10	5	1	0.5	0.1
21 BENZO(e)PYRENE	4058	1.23	100	50	25	10	5	1	0.5	0.1
22 BENZO(a)PYRENE	2968	1.68	100	50	25	10	5	1	0.5	0.1
23 PERYLENE	4480	1.12	100	50	25	10	5	1	0.5	0.1
24 INDENO(1,2,3–c,d)PYRENE	2460	2.03	100	50	25	10	5	1	0.5	0.1
25 DIBENZO(a,h)ANTHRACENE	2978	1.68	100	50	25	10	5	1	0.5	0.1
26 d12–BENZO(ghi)PRYLENE	2460			5	5	5	5	5	5	5
27 BENZO(ghi)PERYLENE	4230	1.18	100	50	25	10	5	1	0.5	0.1

TABLE 2

Retention times, Target Ions and Qualifier Ions

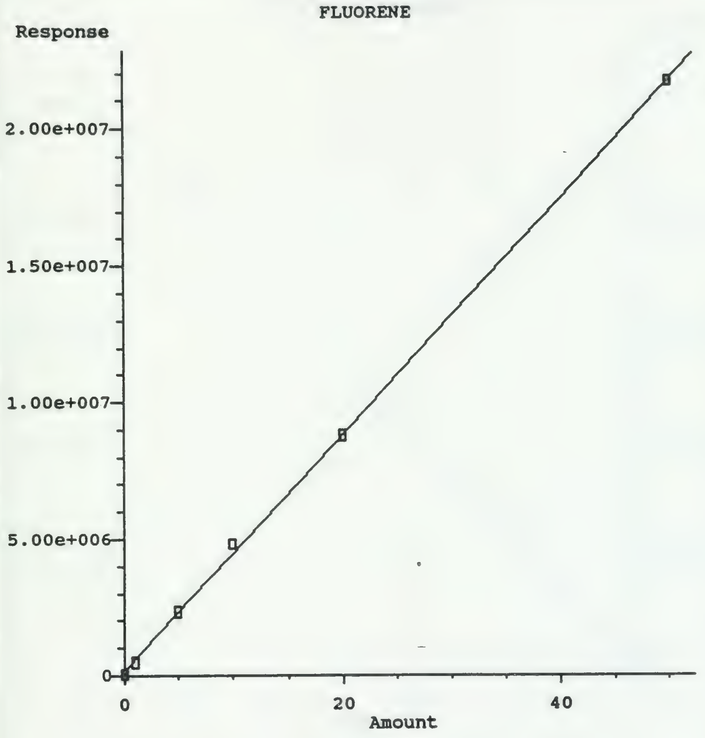
COMPOUNDS	Rt (min)	Target Ion	Qualifier Ions	
			Q1	Q2
1 FLUORENE	9.09	166	165	167
2 DIBENZOTHIOPHENE	10.55	184	185	139
3 d10-PHENANTHRENE	10.72	188		
4 PHENANTHRENE	10.76	178	179	176
5 ANTHRACENE	10.84	178	176	179
6 ACRIDINE	10.9	179		
7 CARBAZOLE	11.11	167	166	139
8 d10-FLUORANTHENE	12.83	212		
9 FLUORANTHENE	12.86	202	203	101
10 PYRENE	13.26	202	200	203
11 RETENE	13.82	234	219	204
12 TETRACOSANE	14.52	57	71	85
13 PENTACOSANE	15.1	57	71	85
14 CHRYSENE	15.37	228	226	114
15 d12-CHRYSENE	15.41	240		
16 1,2-BENZANTHRACENE	15.45	228	226	114
17 HEXACOSANE	15.7	57	71	85
18 OCTACOSANE	17.08	57	71	85
19 BENZO(b+k)FLUORANTHENE	17.73	252	253	125
20 NONACOSANE	17.9	57	71	85
21 BENZO(e)PYRENE	18.44	252	253	125
22 BENZO(a)PYRENE	18.58	252	253	125
23 PERYLENE	18.8	252	250	125
24 INDENO(1,2,3-c,d)PYRENE	22.4	276	277	138
25 DIBENZO(a,h)ANTHRACENE	22.47	278	279	139
26 d12-BENZO(ghi)PRYLENE	23.38	288		
27 BENZO(ghi)PERYLENE	23.49	276	277	138

TABLE 3

EXTRACTION EFFICIENCIES

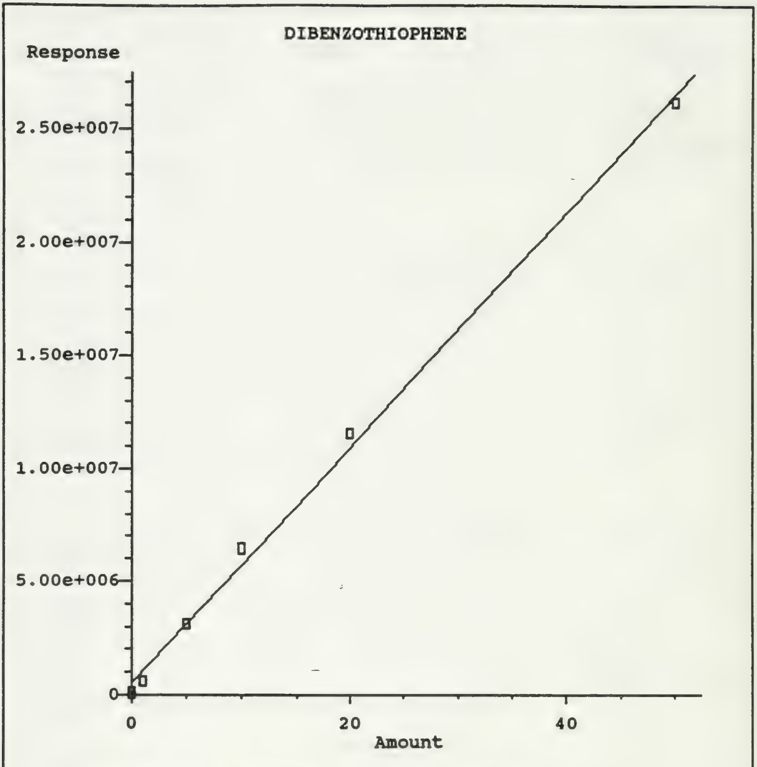
		XAD					WATER					FILTER				
COMPOUNDS	STD SPIKED (ng/ul)	BLANK (ng/ul)	SPIKE1 (ng/ul)	SPIKE (ng/ul)	AVG (ng/ul)	RECOV (%)	BLANK (ng/ul)	SPIKE1 (ng/ul)	SPIKE2 (ng/ul)	AVG (ng/ul)	RECOV. (%)	BLANK (ng/ul)	SPIKE1 (ng/ul)	SPIKE2 (ng/ul)	AVG (ng/ul)	RECOV. (%)
1 FLUORENE	5	ND	3.2	4.0	3.6	72.4	ND	2.8	2.3	2.6	51.0	ND	3.2	1.9	2.6	51.0
2 DIBENZOTHIOPHENE	5	ND	3.2	3.4	3.3	66.4	ND	2.6	2.7	2.7	53.0	ND	2.3	2.3	2.3	46.0
3 d10-PHENANTHRENE(surr.)	5	ND	3.2	4.0	3.6	72.4	ND	6.6	6.0	6.3	97.0	ND	3.2	2.7	3.0	76.0
4 PHENANTHRENE	5	ND	3.6	4.4	4.0	80.0	ND	3.5	3.2	3.4	67.0	ND	3.3	2.9	3.1	62.0
5 ANTHRACENE	5	ND	3.7	4.2	4.0	79.2	ND	4.1	4.1	4.1	82.0	ND	3.9	3.9	3.9	78.0
6 ACRIDINE	5	ND	0.7	0.3	0.5	10.2	ND	0.8	0.8	0.8	16.0	ND	0.8	0.8	0.8	16.0
7 CARBAZOLE	5	ND	2.4	3.9	3.2	63.0	ND	2.5	3.2	2.9	57.0	ND	2.9	2.4	2.7	53.0
8 d10-FLUORANTHENE(perfor.)																
9 FLUORANTHENE	5	ND	3.8	4.7	4.3	85.4	ND	3.6	3.8	3.7	74.0	ND	3.4	3.4	3.4	68.0
10 PYRENE	5	ND	3.6	4.3	4.0	79.0	ND	3.7	3.8	3.8	75.0	ND	3.4	3.6	3.5	70.0
11 RETENE	5	ND	3.6	4.2	3.9	78.0	ND	3.6	3.8	3.7	74.0	ND	3.3	3.5	3.4	68.0
12 TETRACOSANE	5	ND	4.4	5.3	4.9	97.4	ND	5.0	4.6	4.8	96.0	ND	3.9	4.9	4.4	88.0
13 PENTACOSANE	5	ND	4.7	5.1	4.9	97.8	ND	5.2	4.6	4.9	98.0	ND	4.1	4.9	4.5	90.0
14 CHRYSENE	5	ND	3.7	4.3	4.0	80.2	ND	3.6	4.1	3.9	77.0	ND	3.4	3.4	3.4	68.0
15 d12-CHRYSENE(surr.)	5	ND	7.2	8.6	7.9	89.0	ND	3.4	3.9	3.7	73.0	ND	6.8	6.7	6.8	84.0
16 1,2-BENZANTHRACENE	5	ND	3.6	4.5	4.1	81.0	ND	3.6	4.1	3.9	77.0	ND	3.7	3.5	3.6	72.0
17 HEXACOSANE	5	ND	4.7	4.8	4.7	94.8	ND	5.2	4.6	4.9	98.0	ND	4.0	4.8	4.4	88.0
18 OCTACOSANE	5	ND	4.3	4.3	4.3	86.2	ND	5.0	4.5	4.8	95.0	ND	3.9	4.6	4.3	85.0
19 BENZO(b+k)FLUORANTHENE	10	ND	6.5	8.4	7.4	74.4	ND	11.2	12.8	12.0	120.0	ND	5.4	10.4	7.9	79.0
20 NONACOSANE	5	ND	4.6	4.0	4.3	85.6	ND	5.4	4.7	5.1	101.0	ND	4.2	4.9	4.6	91.0
21 BENZO(e)PYRENE	5	ND	3.7	3.0	3.4	67.2	ND	3.6	4.1	3.9	77.0	ND	3.4	3.3	3.4	67.0
22 BENZO(a)PYRENE	5	ND	3.7	4.0	3.9	77.2	ND	3.5	4.1	3.8	76.0	ND	3.4	3.3	3.4	67.0
23 PERYLENE	5	ND	3.7	4.1	3.9	78.2	ND	3.4	4.0	3.7	74.0	ND	3.1	3.1	3.1	62.0
24 INDENO(1,2,3-c,d)PYRENE	5	ND	4.2	4.7	4.5	89.0	ND	3.7	4.2	4.0	79.0	ND	3.7	3.3	3.5	70.0
25 DIBENZO(a.h)ANTHRACENE	5	ND	4.2	4.7	4.5	89.0	ND	3.6	4.2	3.9	78.0	ND	3.7	3.2	3.5	69.0
26 d12-BENZO(ghi)PRYLENE(per.)																
27 BENZO(ghi)PERYLENE	5	ND	4.2	4.7	4.5	89.0	ND	3.8	4.2	4.0	80.0	ND	3.6	3.3	3.5	69.0

F-1



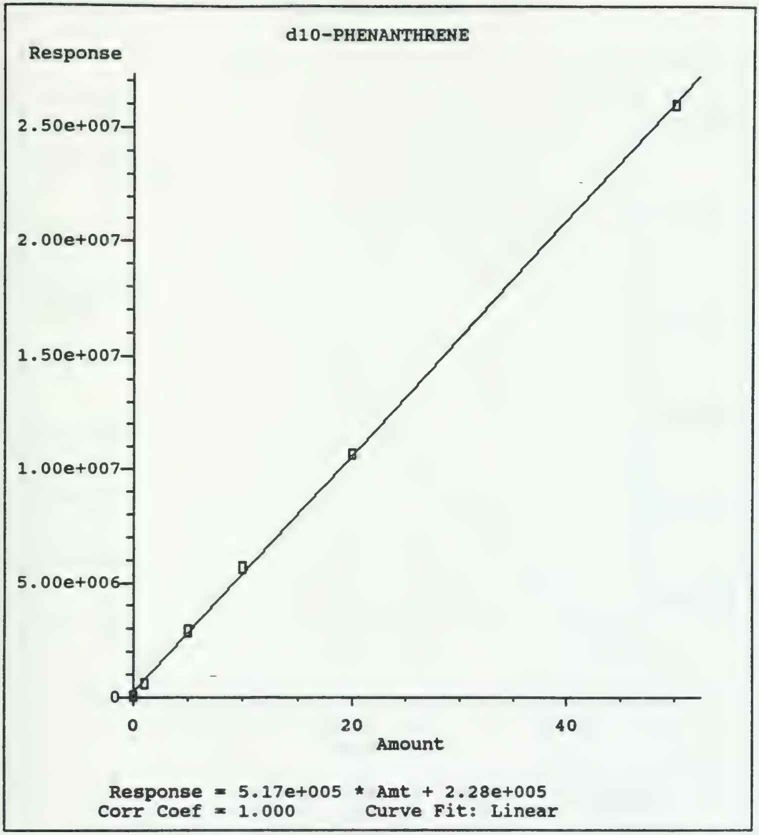
Response = 4.33e+005 * Amt + 1.60e+005
Corr Coef = 1.000 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:22:09 1991



Response = 5.19e+005 * Amt + 5.36e+005
Corr Coef = 0.997 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:24:16 1991



Response = 5.17e+005 * Amt + 2.28e+005
Corr Coef = 1.000   Curve Fit: Linear

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Method Name:  C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:24:38 1991  .
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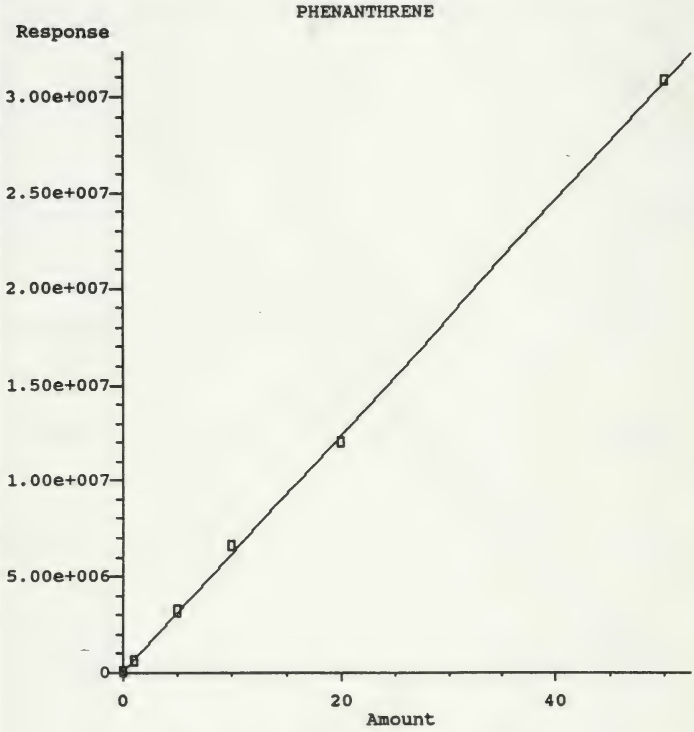
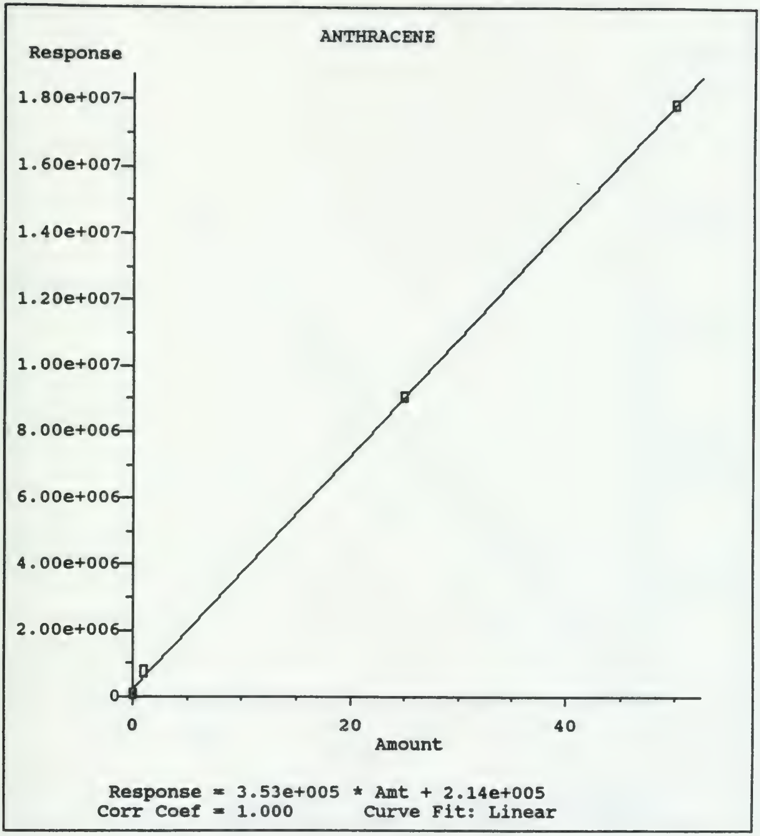


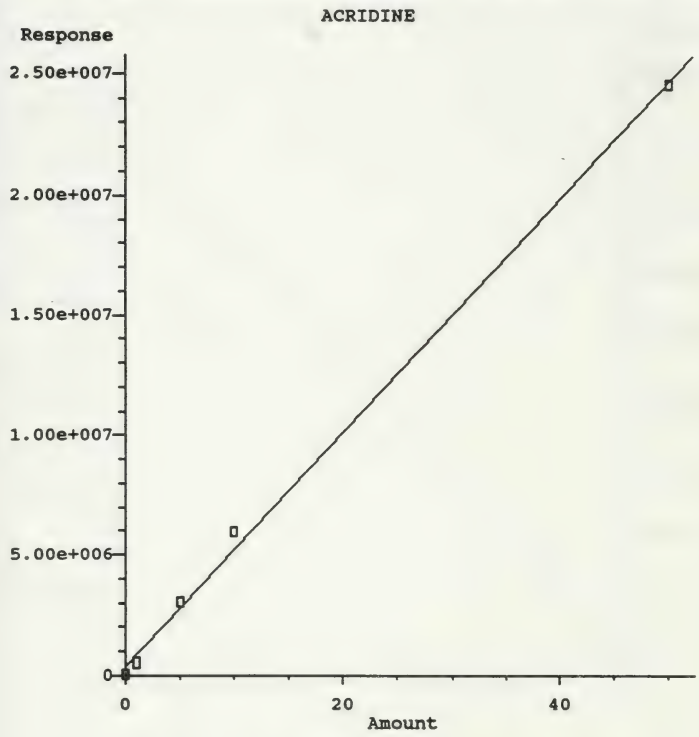
Response = 6.13e+005 * Amt + 8.28e+004
Corr Coef = 1.000 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:25:04 1991



Response = 3.53e+005 * Amt + 2.14e+005
Corr Coef = 1.000 Curve Fit: Linear

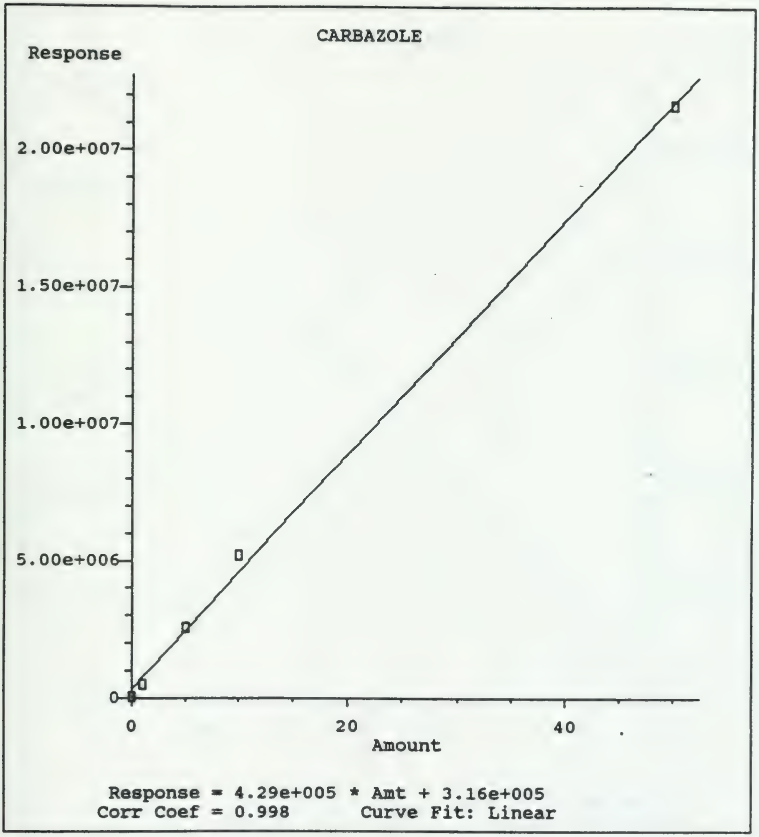
Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:25:21 1991



Response = 4.86e+005 * Amt + 3.96e+005
Corr Coef = 0.998 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:27:58 1991

F. 2

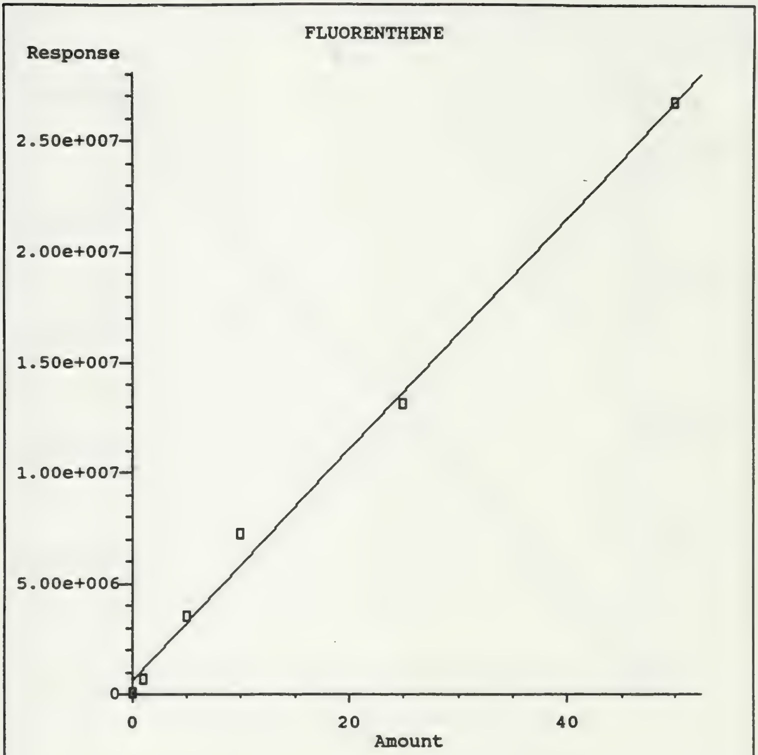


CARBAZOLE

Response = 4.29e+005 * Amt + 3.16e+005
Corr Coef = 0.998 Curve Fit: Linear

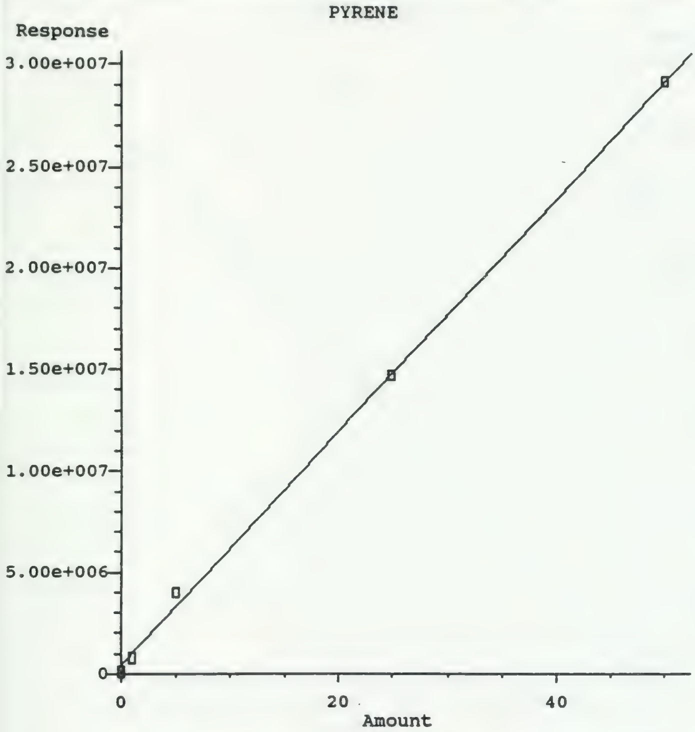
Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:28:51 1991

F-8



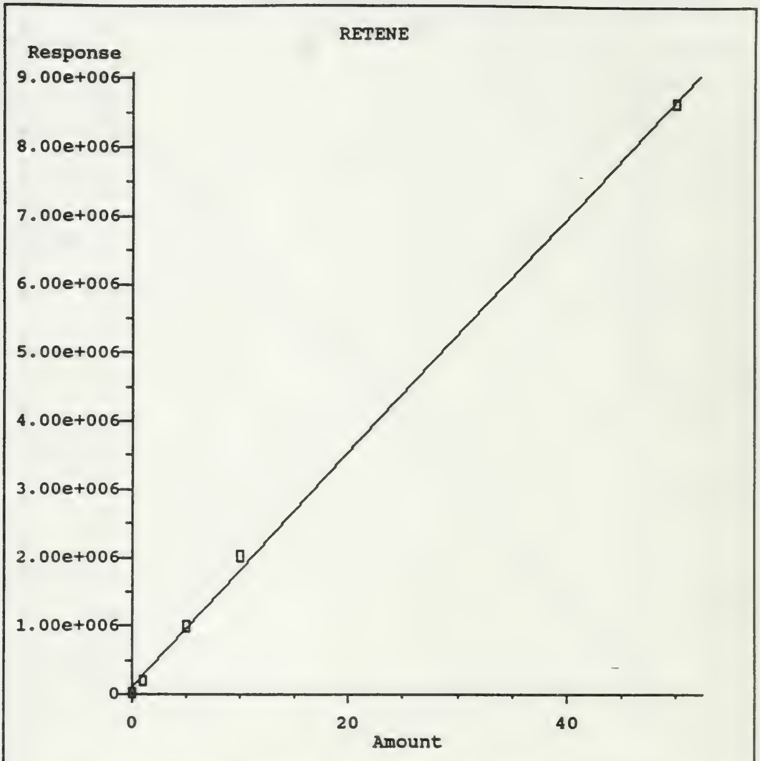
Response = 5.22e+005 * Amt + 6.39e+005
Corr Coef = 0.994 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:29:12 1991



Response = 5.76e+005 * Amt + 4.25e+005
Corr Coef = 0.999   Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:29:12 1991



Response = 1.72e+005 * Amt + 1.07e+005
Corr Coef = 0.999 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
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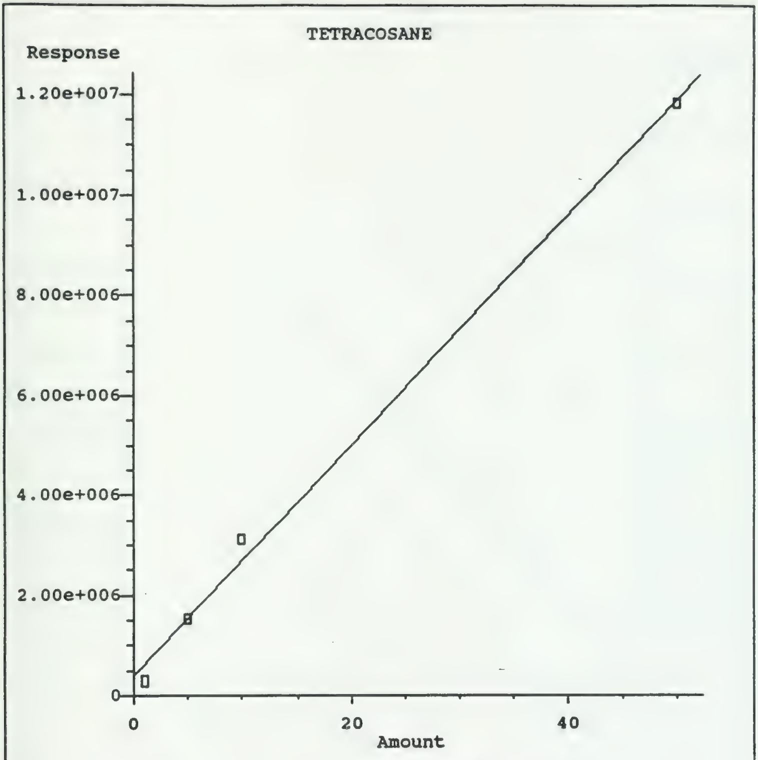
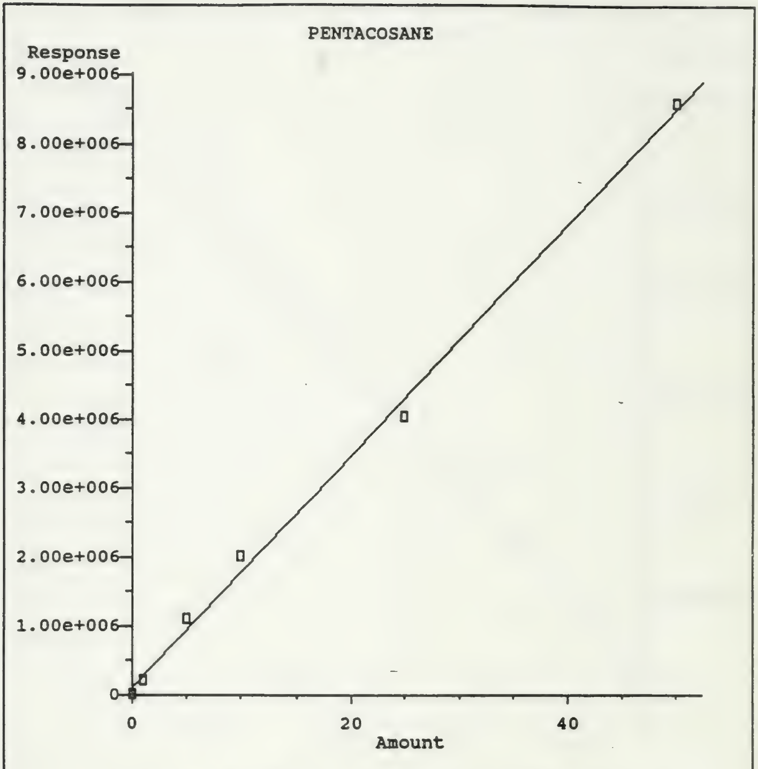


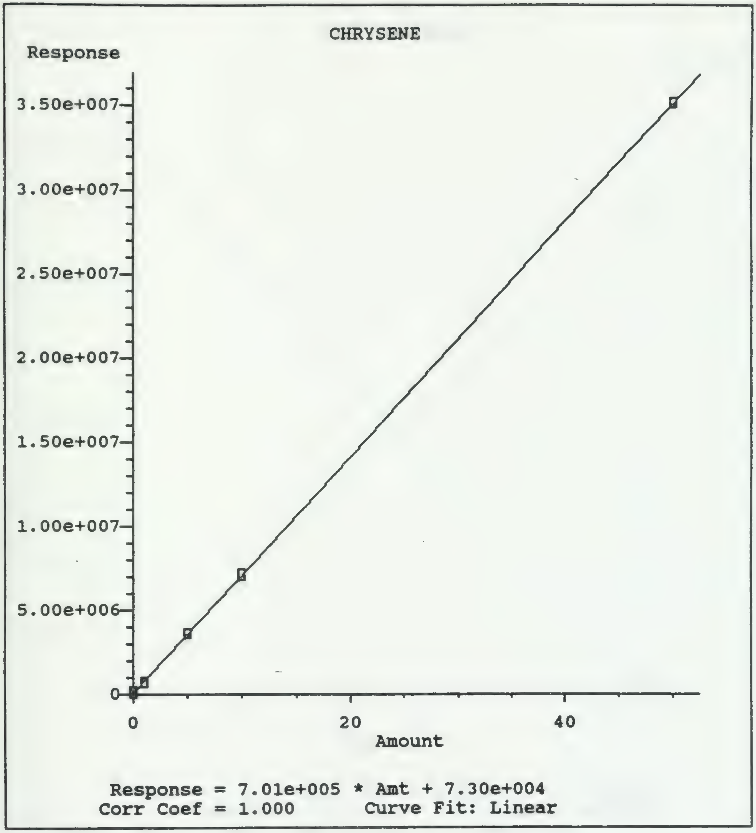
Response = 2.30e+005 * Amt + 3.86e+005
Corr Coef = 0.996 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:30:26 1991



Response = 1.68e+005 * Amt + 1.18e+005
Corr Coef = 0.997 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:31:12 1991

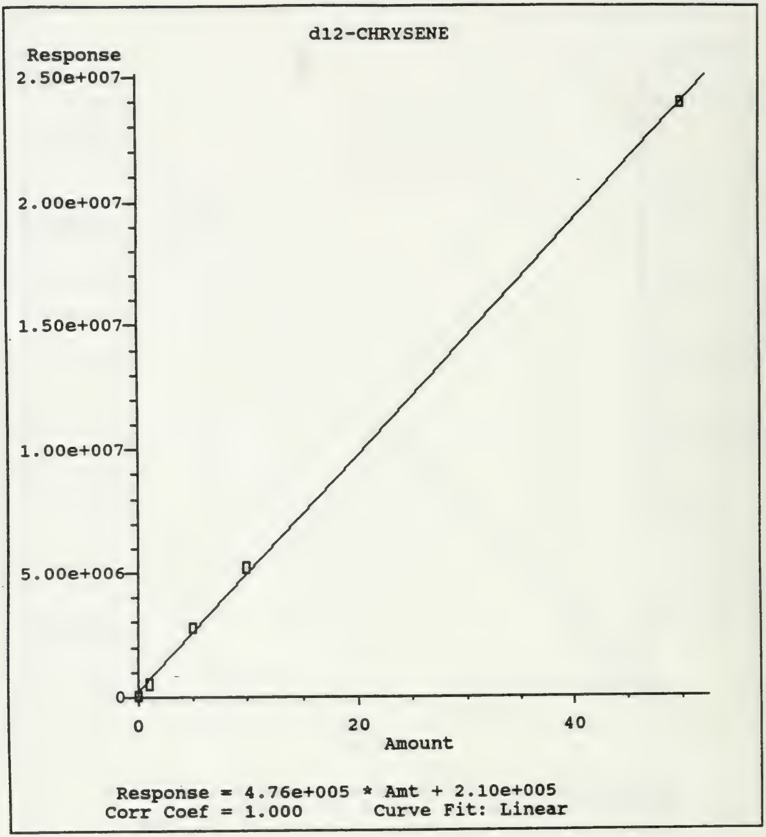


CHRYSENE

Response = 7.01e+005 * Amt + 7.30e+004
Corr Coef = 1.000 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:31:12 1991

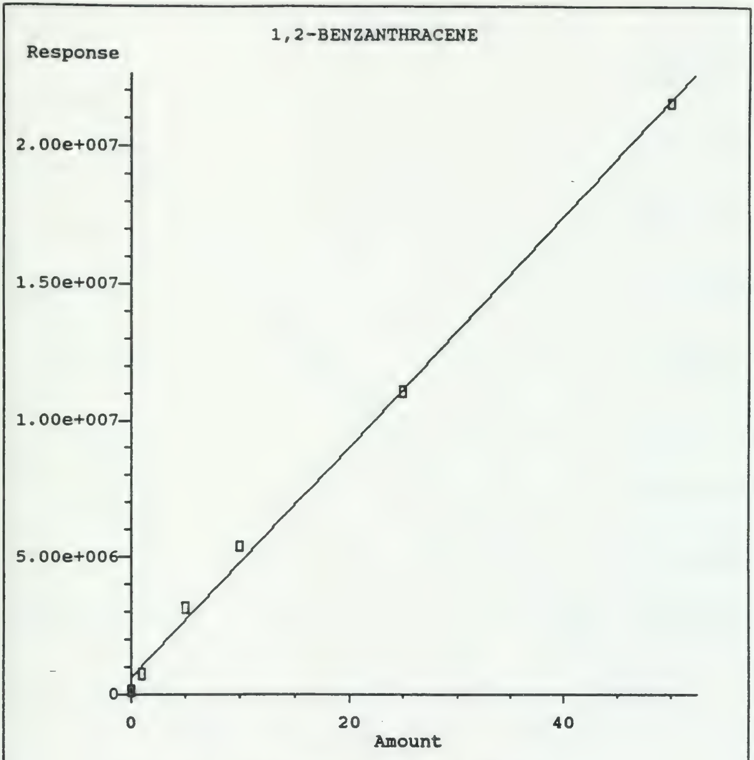
F-11/7



Response = 4.76e+005 * Amt + 2.10e+005
Corr Coef = 1.000 Curve Fit: Linear

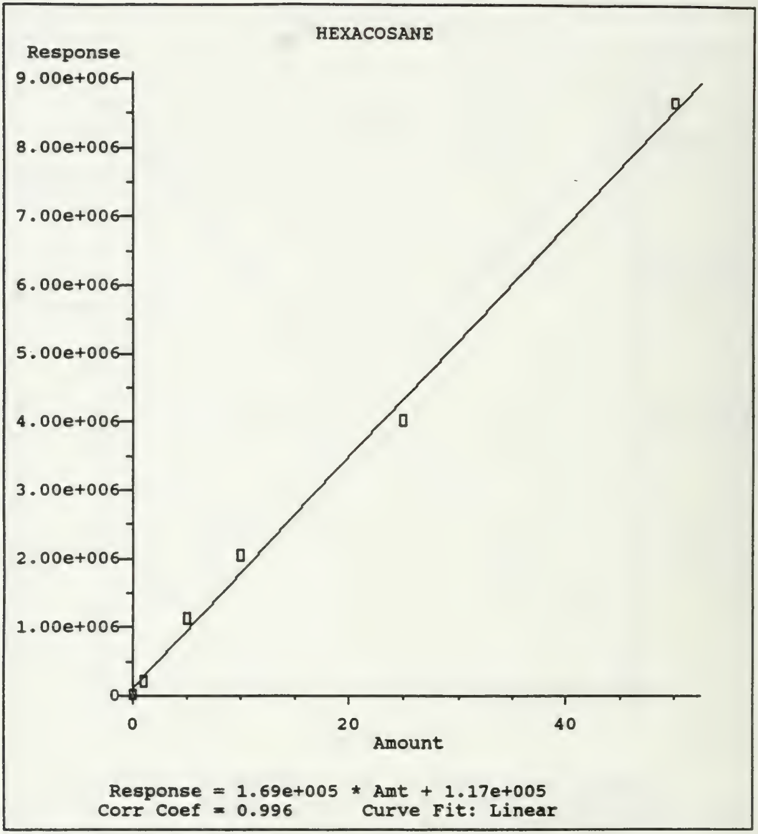
Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:31:43 1991

F-15



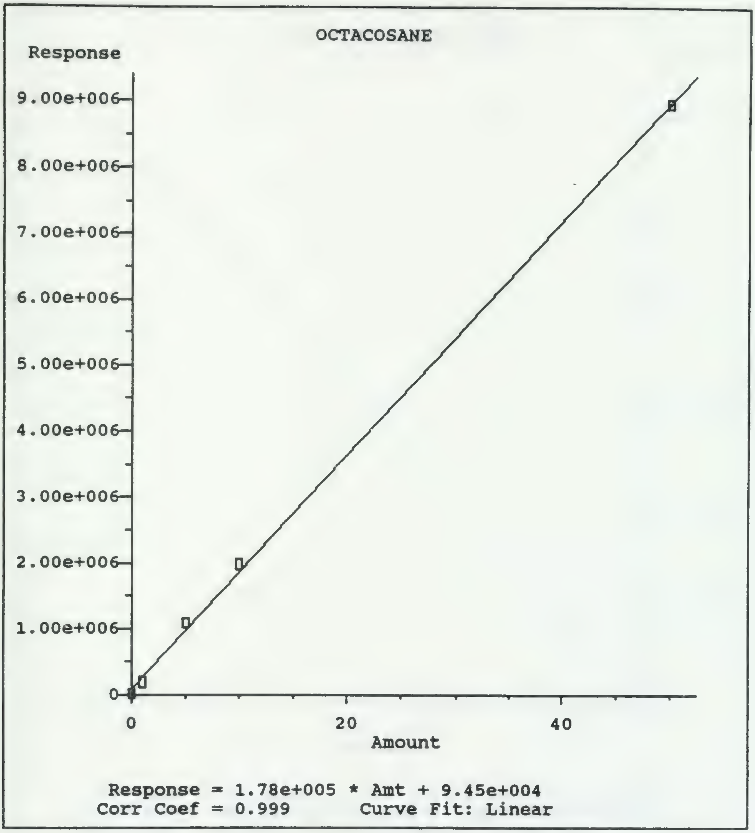
Response = 4.21e+005 * Amt + 6.10e+005
Corr Coef = 0.997 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:32:04 1991 .



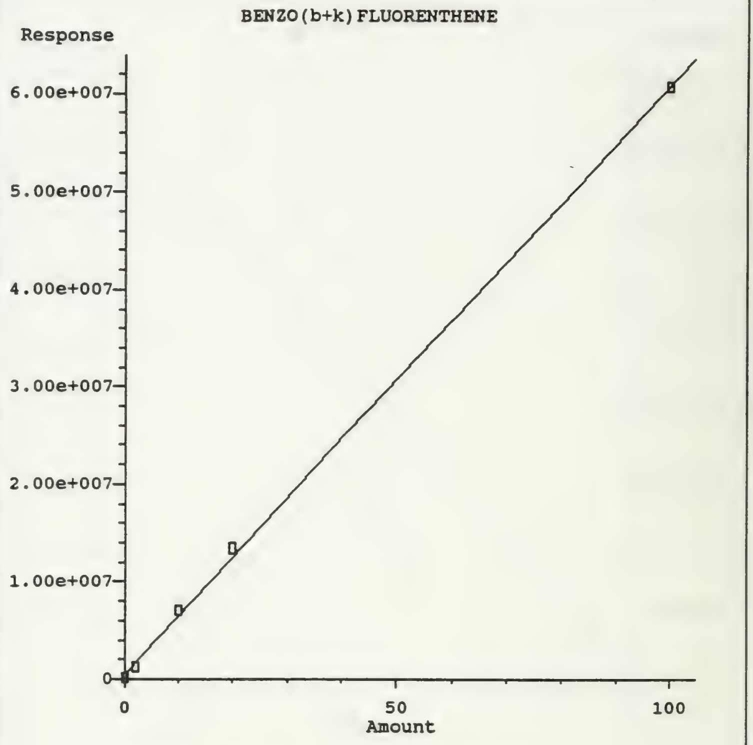
Response = 1.69e+005 * Amt + 1.17e+005
Corr Coef = 0.996 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:32:04 1991



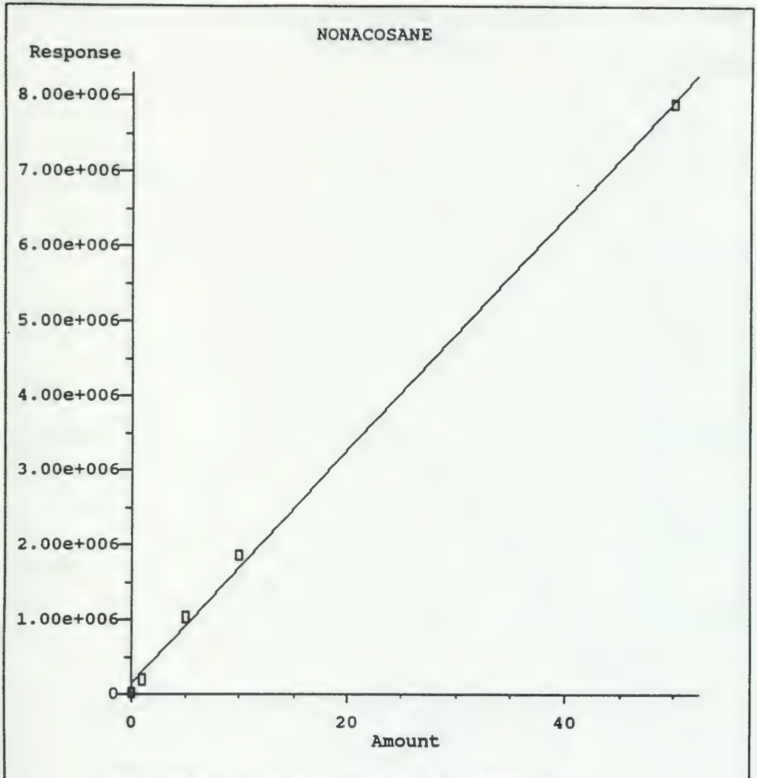
Response = 1.78e+005 * Amt + 9.45e+004
Corr Coef = 0.999 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:32:04 1991



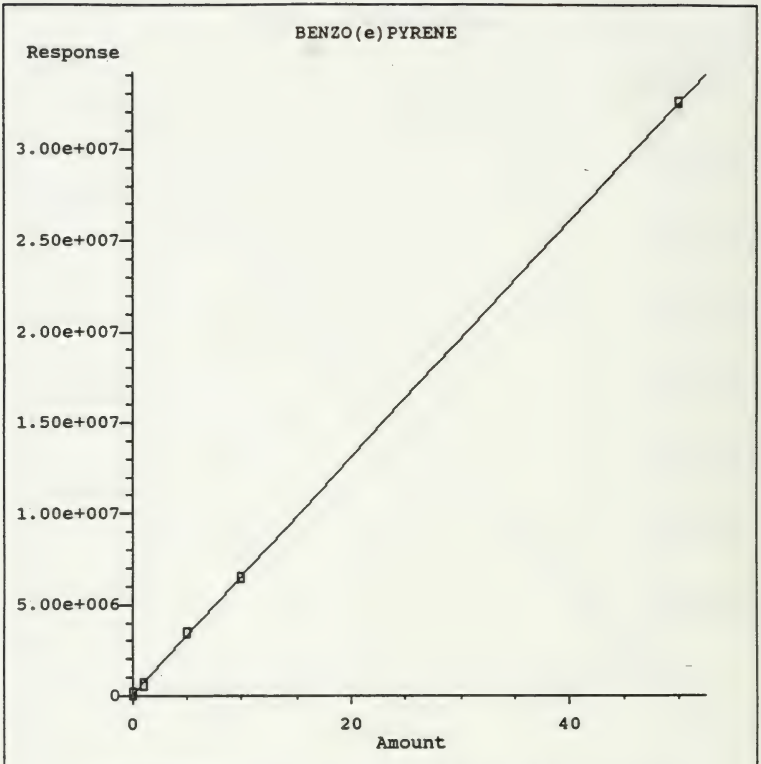
Response = 6.05e+005 * Amt + 5.33e+005
Corr Coef = 0.999 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:32:47 1991



Response = 1.56e+005 * Amt + 1.36e+005
Corr Coef = 0.998 Curve Fit: Linear

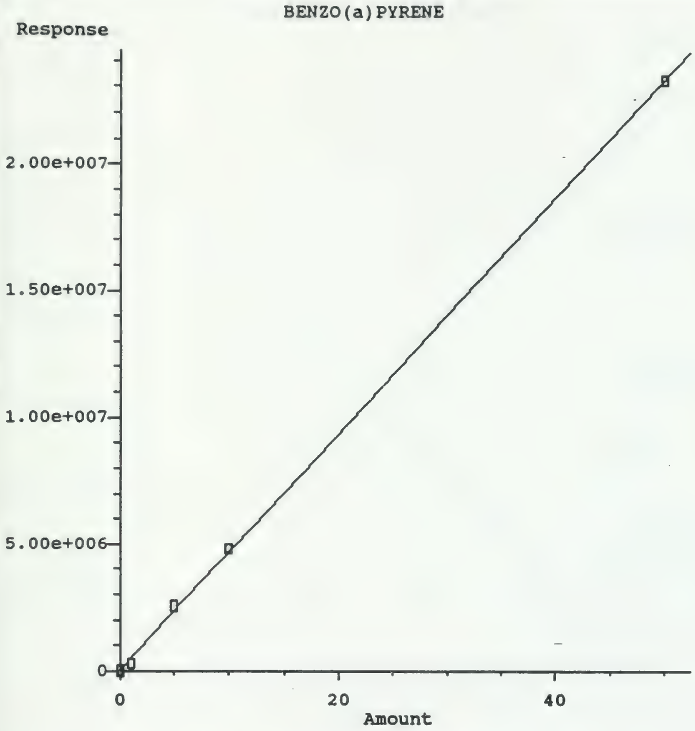
Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:33:05 1991



Response = 6.50e+005 * Amt + 4.33e+004
Corr Coef = 1.000 Curve Fit: Linear

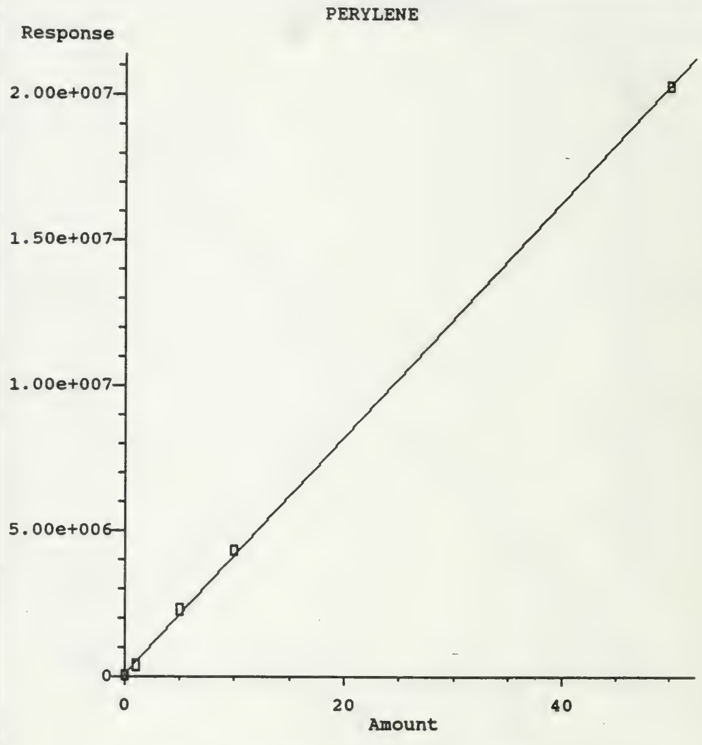
Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:33:24 1991

F- 21



Response = 4.65e+005 * Amt + 3.56e+004
Corr Coef = 1.000   Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:33:43 1991

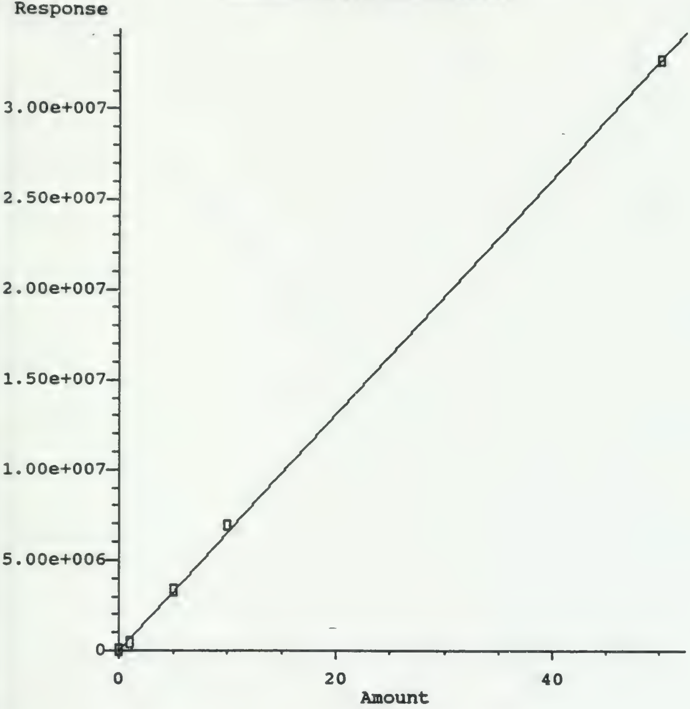


Response = 4.06e+005 * Amt + 1.09e+005
Corr Coef = 1.000 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:34:01 1991

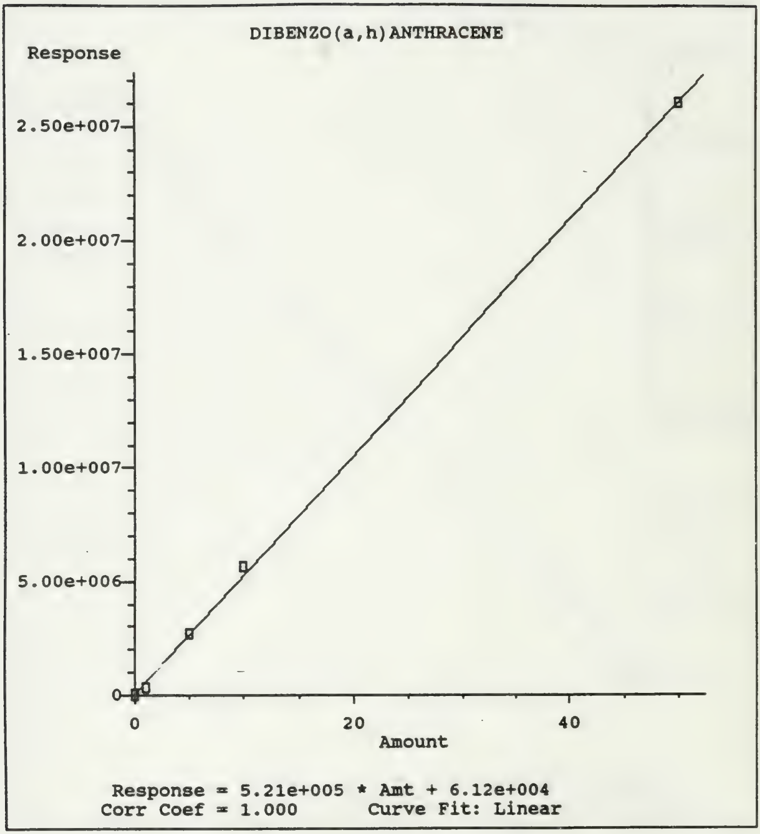
F-27

INDENO((1,2,3-c,d)PYRENE



Response = 6.55e+005 * Amt + 3.40e+004
Corr Coef = 1.000 Curve Fit: Linear

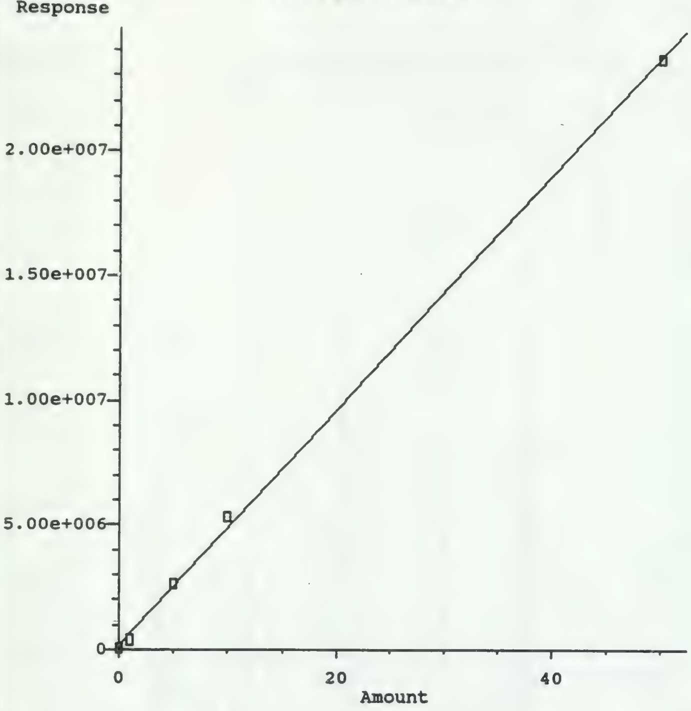
Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:34:21 1991



DIBENZO(a,h)ANTHRACENE

Response = 5.21e+005 * Amt + 6.12e+004
Corr Coef = 1.000 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:34:42 1991



BENZO(ghi)PERYLENE

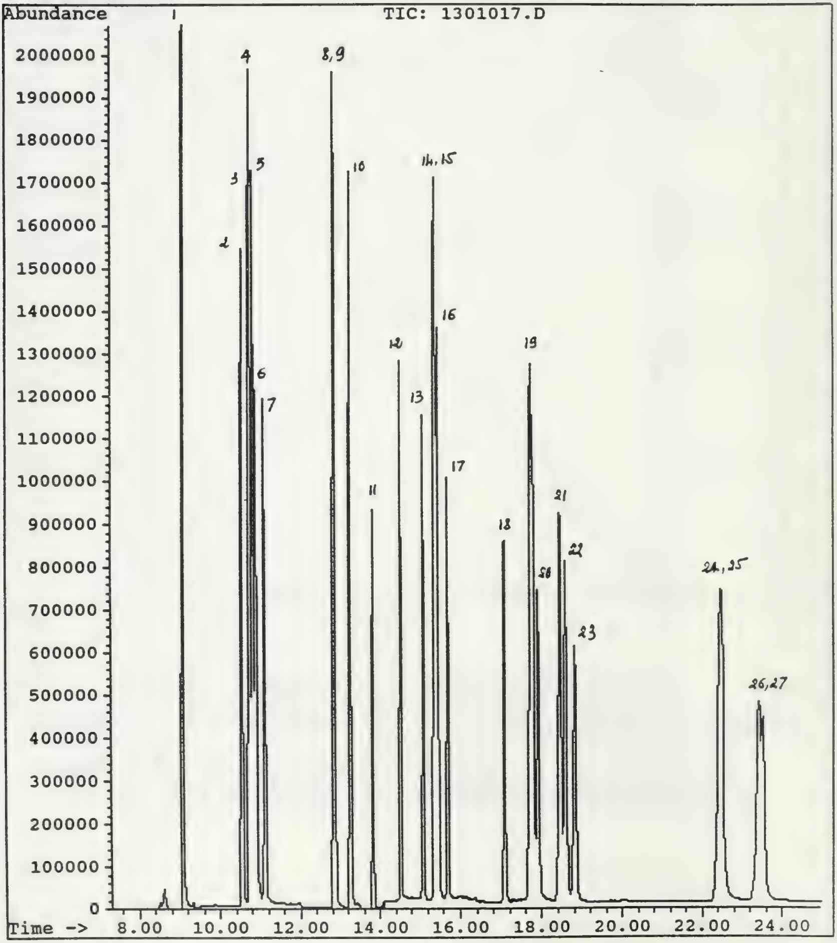
Response = 4.72e+005 * Amt + 1.82e+005
Corr Coef = 0.999 Curve Fit: Linear

Method Name: C:\CHEMPC\METHODS\PAHM5.M
Calibration Table Last Updated: Thu Sep 05 09:35:06 1991

F-a°5

File: C:\CHEMPC\DATA\PAHMSE1.D\1301017.D
Operator: QUANG TRAN
Date Acquired: 4 Jul 91 8:40 am
Method File: PAHM.M
Sample Name: STD-4
Misc Info:
ALS vial: 13

5 ng/µl



F-27

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File:           C:\CHEMPC\DATA\PAHMSE1.D\0801012.D
Operator:       QUANG TRAN
Date Acquired:   3 Jul 91   6:31 pm
Method File:    PAHM.M
Sample Name:                        STD-7
Misc Info:
ALS vial:       8
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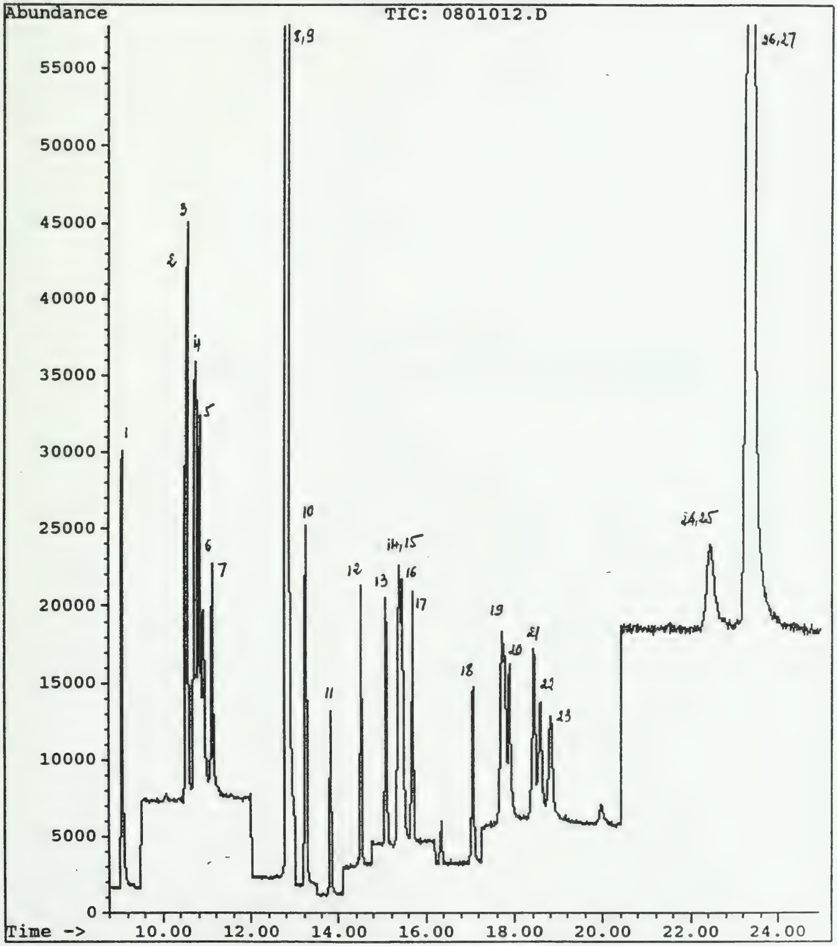
0.1 ng/µl



APPENDIX A-4

INORGANIC SAMPLE DIGESTION AND ANALYSIS PROCEDURES

METHOD 6010

INDUCTIVELY COUPLED PLASMA ATOMIC EMISSION SPECTROSCOPY

1.0 SCOPE AND APPLICATION

1.1 Inductively coupled plasma atomic emission spectroscopy (ICP) determines elements including metals in solution. The method is applicable to a large number of metals and wastes. All matrices, including ground water, aqueous samples, EP extracts, industrial wastes, soils, sludges, sediments, and other solid wastes, require digestion prior to analysis.

1.2 Elements for which Method 6010 is applicable are listed in Table 1. Detection limits, sensitivity, and optimum ranges of the metals will vary with the matrices and model of spectrometer. The data shown in Table 1 provide concentration ranges for clean aqueous samples. Use of this method is restricted to spectroscopists who are knowledgeable in the correction of spectral, chemical, and physical interferences.

1.3 The method of standard addition (MSA) (Paragraph 8.5.3) shall be used for the analysis of all EP extracts and sample digests unless either serial dilution or matrix spike addition demonstrates that it is not required.

2.0 SUMMARY OF METHOD

2.1 Prior to analysis, samples must be solubilized or digested using appropriate Sample Preparation Methods (e.g., Methods 3005-3050).

2.2 Method 6010 describes the simultaneous, or sequential, multielemental determination of elements by ICP. The method measures element-emitted light by optical spectrometry. Samples are nebulized and the resulting aerosol is transported to the plasma torch. Element-specific atomic-line emission spectra are produced by a radio-frequency inductively coupled plasma. The spectra are dispersed by a grating spectrometer, and the intensities of the lines are monitored by photomultiplier tubes. Background correction is required for trace element determination. Background must be measured adjacent to analyte lines on samples during analysis. The position selected for the background-intensity measurement, on either or both sides of the analytical line, will be determined by the complexity of the spectrum adjacent to the analyte line. The position used must be free of spectral interference and reflect the same change in background intensity as occurs at the analyte wavelength measured. Background correction is not required in cases of line broadening where a background correction measurement would actually degrade the analytical result. The possibility of additional interferences named in Section 3.0 should also be recognized and appropriate corrections made; tests for their presence are described in Section 8.5.

TABLE 1. RECOMMENDED WAVELENGTHS AND ESTIMATED INSTRUMENTAL DETECTION LIMITS

Element	Wavelength[a] (nm)	Estimated Detection Limit[b] (ug/L)
Aluminum	308.215	45
Antimony	206.833	32
Arsenic	193.696	53
Barium	455.403	2
Beryllium	313.042	0.3
Boron	249.773	5
Cadmium	226.502	4
Calcium	317.933	10
Chromium	267.716	7
Cobalt	228.616	7
Copper	324.754	6
Iron	259.940	7
Lead	220.353	42
Magnesium	279.079	30
Manganese	257.610	2
Molybdenum	202.030	8
Nickel	231.604	15
Potassium	766.491	See note c
Selenium	196.026	75
Silicon	288.158	58
Silver	328.068	7
Sodium	588.995	29
Thallium	190.864	40
Vanadium	292.402	8
Zinc	213.856	2

[a] The wavelengths listed are recommended because of their sensitivity and overall acceptance. Other wavelengths may be substituted if they can provide the needed sensitivity and are treated with the same corrective techniques for spectral interference (see Paragraph 3.1). In time, other elements may be added as more information becomes available and as required.

[b] The estimated instrumental detection limits shown are taken from Reference 1 in Section 10.0 below. They are given as a guide for an instrumental limit. The actual method detection limits are sample dependent and may vary as the sample matrix varies.

[c] Highly dependent on operating conditions and plasma position.

3.0 INTERFERENCES

3.1 Spectral interferences are caused by: (1) overlap of a spectral line from another element; (2) unresolved overlap of molecular band spectra; (3) background contribution from continuous or recombination phenomena; and (4) stray light from the line emission of high-concentration elements. Spectral overlap can be compensated for by computer-correcting the raw data after monitoring and measuring the interfering element. Unresolved overlap requires selection of an alternate wavelength. Background contribution and stray light can usually be compensated for by a background correction adjacent to the analyte line.

Users of simultaneous multielement instruments must verify the absence of spectral interference from an element in a sample for which there is no instrument detection channel. Potential spectral interferences for the recommended wavelengths are given in Table 2. The data in Table 2 are intended as rudimentary guides for indicating potential interferences; for this purpose, linear relations between concentration and intensity for the analytes and the interferents can be assumed.

3.1.1 The interference is expressed as analyte concentration equivalents (i.e., false analyte concentrations) arising from 100 mg/L of the interference element. For example, assume that As is to be determined (at 193.696 nm) in a sample containing approximately 10 mg/L of Al. According to Table 2, 100 mg/L of Al would yield a false signal for As equivalent to approximately 1.3 mg/L. Therefore, the presence of 10 mg/L of Al would result in a false signal for As equivalent to approximately 0.13 mg/L. The user is cautioned that other instruments may exhibit somewhat different levels of interference than those shown in Table 2. The interference effects must be evaluated for each individual instrument since the intensities will vary with operating conditions, power, viewing height, argon flow rate, etc.

3.1.2 The dashes in Table 2 indicate that no measurable interferences were observed even at higher interferent concentrations. Generally, interferences were discernible if they produced peaks, or background shifts, corresponding to 2 to 5% of the peaks generated by the analyte concentrations.

3.1.3 At present, information on the listed silver and potassium wavelengths is not available, but it has been reported that second-order energy from the magnesium 383.231-nm wavelength interferes with the listed potassium line at 766.491 nm.

3.2 Physical interferences are effects associated with the sample nebulization and transport processes. Changes in viscosity and surface tension can cause significant inaccuracies, especially in samples containing high dissolved solids or high acid concentrations. If physical interferences are present, they must be reduced by diluting the sample, by using a peristaltic pump or by using the standard additions method. Another problem that can occur with high dissolved solids is salt buildup at the tip of the nebulizer, which affects aerosol flow rate and causes instrumental drift. The problem can be controlled by wetting the argon prior to nebulization, using a

TABLE 2. ANALYTE CONCENTRATION EQUIVALENTS ARISING FROM INTERFERENCE AT THE 100-mg/L LEVEL

Analyte	Wavelength (nm)	Interferent[a,b]									
		Al	Ca	Cr	Cu	Fe	Mg	Mn	Ni	Tl	V
Aluminum	308.215	—	—	—	—	—	—	0.21	—	—	1.4
Antimony	206.833	0.47	—	2.9	—	0.08	—	—	—	0.25	0.45
Arsenic	193.696	1.3	—	0.44	—	—	—	—	—	—	1.1
Barium	455.403	—	—	—	—	—	—	—	—	—	—
Beryllium	313.042	—	—	—	—	—	—	—	—	0.04	0.05
Boron	249.773	0.04	—	—	—	0.32	—	—	—	—	—
Cadmium	226.502	—	—	—	—	0.03	—	—	0.02	—	—
Calcium	317.933	—	—	0.08	—	0.01	0.01	0.04	—	0.03	0.03
Chromium	267.716	—	—	—	—	0.003	—	0.04	—	—	0.04
Cobalt	228.616	—	—	0.03	—	0.005	—	—	0.03	0.15	—
Copper	324.754	—	—	—	—	0.003	—	—	—	0.05	0.02
Iron	259.940	—	—	—	—	—	—	0.12	—	—	—
Lead	220.353	0.17	—	—	—	—	—	—	—	—	—
Magnesium	279.079	—	0.02	0.11	—	0.13	—	0.25	—	0.07	0.12
Manganese	257.610	0.005	—	0.01	—	0.002	0.002	—	—	—	—
Molybdenum	202.030	0.05	—	—	—	0.03	—	—	—	—	—
Nickel	231.604	—	—	—	—	—	—	—	—	—	—
Selenium	196.026	0.23	—	—	—	0.09	—	—	—	—	—
Silicon	288.158	—	—	0.07	—	—	—	—	—	—	0.01
Sodium	588.995	—	—	—	—	—	—	—	—	0.08	—
Thallium	190.864	0.30	—	—	—	—	—	—	—	—	—
Vanadium	292.402	—	—	0.05	—	0.005	—	—	—	0.02	—
Zinc	213.856	—	—	—	0.14	—	—	—	0.29	—	—

[a] Dashes indicate that no interference was observed even when interferents were introduced at the following levels:

Al - 1000 mg/L,	Mg - 1000 mg/L,
Ca - 1000 mg/L,	Mn - 200 mg/L,
Cr - 200 mg/L,	Tl - 200 mg/L,
Cu - 200 mg/L	V - 200 mg/L
Fe - 1000 mg/L	

[b] The figures recorded as analyte concentrations are not the actual observed concentrations; to obtain those figures, add the listed concentration to the interferent figure.

tip washer, or diluting the sample. Also, it has been reported that better control of the argon flow rate improves instrument performance; this is accomplished with the use of mass flow controllers.

3.3 Chemical interferences include molecular compound formation, ionization effects, and solute vaporization effects. Normally, these effects are not significant with the ICP technique. If observed, they can be minimized by careful selection of operating conditions (incident power, observation position, and so forth), by buffering of the sample, by matrix matching, and by standard addition procedures. Chemical interferences are highly dependent on matrix type and the specific analyte element.

4.0 APPARATUS AND MATERIALS

4.1 Inductively coupled argon plasma emission spectrometer:

4.1.1 Computer-controlled emission spectrometer with background correction.

4.1.2 Radio frequency generator.

4.1.3 Argon gas supply: Welding grade or better.

4.2 Operating conditions: The analyst should follow the instructions provided by the instrument's manufacturer. For operation with organic solvents, use of the auxiliary argon inlet is recommended, as are solvent-resistant tubing, increased plasma (coolant) argon flow, decreased nebulizer flow, and increased RF power to obtain stable operation and precise measurements. Sensitivity, instrumental detection limit, precision, linear dynamic range, and interference effects must be established for each individual analyte line on that particular instrument. All measurements must be within instrument linear range where coordination factors are valid. The analyst must (1) verify that the instrument configuration and operating conditions satisfy the analytical requirements and (2) maintain quality control data confirming instrument performance and analytical results.

5.0 REAGENTS

5.1 Acids used in the preparation of standards and for sample processing must be reagent grade or better. Redistilled acids may be used.

5.1.1 Concentrated hydrochloric acid (HCl).

5.1.2 Hydrochloric acid (1:1): Add 500 mL concentrated HCl to 400 mL Type II water and dilute to 1 liter.

5.1.3 Concentrated nitric acid (HNO_3).

5.1.4 Nitric acid (1:1): Add 500 mL concentrated HNO_3 to 400 mL Type II water and dilute to 1 liter.

5.2 ASTM Type II water (ASTM D1193): Water should be monitored for impurities.

5.3 Standard stock solutions may be purchased or prepared from ultra-high purity grade chemicals or metals (99.99 to 99.999% pure). All salts must be dried for 1 hr at 105°C, unless otherwise specified.

(CAUTION: Many metal salts are extremely toxic if inhaled or swallowed. Wash hands thoroughly after handling.)

Typical stock solution preparation procedures follow. Concentrations are calculated based upon the weight of pure metal added, or with the use of the mole fraction and the weight of the metal salt added.

Metal

$$\text{Concentration (ppm)} = \frac{\text{weight (mg)}}{\text{volume (L)}}$$

Metal salts

$$\text{Concentration (ppm)} = \frac{\text{weight (mg)} \times \text{mole fraction}}{\text{volume (L)}}$$

5.3.1 Aluminum solution, stock, 1 mL = 100 ug Al: Dissolve 0.10 g of aluminum metal, weighed accurately to at least four significant figures, in an acid mixture of 4 mL of (1:1) HCl and 1 mL of concentrated HNO_3 in a beaker. Warm gently to effect solution. When solution is complete, transfer quantitatively to a liter flask, add an additional 10 mL of (1:1) HCl and dilute to 1,000 mL with Type II water.

5.3.2 Antimony solution, stock, 1 mL = 100 ug Sb: Dissolve 0.27 g $K(SbO)C_4H_4O_6$ (mole fraction Sb = 0.3749), weighed accurately to at least four significant figures, in Type II water, add 10 mL (1:1) HCl, and dilute to 1,000 mL with Type II water.

5.3.3 Arsenic solution, stock, 1 mL = 100 ug As: Dissolve 0.13 g of As_2O_3 (mole fraction As = 0.7574), weighed accurately to at least four significant figures, in 100 mL of Type II water containing 0.4 g NaOH. Acidify the solution with 2 mL concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.3.4 Barium solution, stock, 1 mL = 100 ug Ba: Dissolve 0.15 g $BaCl_2$ (mole fraction Ba = 0.6595), dried at 250°C for 2 hr, weighed accurately to at least four significant figures, in 10 mL Type II water with 1 mL (1:1) HCl. Add 10.0 mL (1:1) HCl and dilute to 1,000 mL with Type II water.

5.3.5 Beryllium solution, stock, 1 mL = 100 ug Be: Do not dry. Dissolve 1.97 g $BeSO_4 \cdot 4H_2O$ (mole fraction Be = 0.0509), weighed accurately to at least four significant figures, in Type II water, add 10.0 ml concentrated HNO_3, and dilute to 1,000 mL with Type II water. Mole fraction = 0.0509.

5.3.6 Boron solution, stock 1 mL = 100 ug B: Do not dry. Dissolve 0.57 g anhydrous H_3BO_3 (mole fraction B = 0.1748), weighed accurately to at least four significant figures, in Type II water and dilute to 1,000 mL. Use a reagent meeting ACS specifications, keep the bottle tightly stoppered, and store in a desiccator to prevent the entrance of atmospheric moisture.

5.3.7 Cadmium solution, stock, 1 mL = 100 ug Cd: Dissolve 0.11 g CdO (mole fraction Cd = 0.8754), weighed accurately to at least four significant figures, in a minimum amount of (1:1) HNO_3. Heat to increase rate of dissolution. Add 10.0 mL concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.3.8 Calcium solution, stock, 1 mL = 100 ug Ca: Suspend 0.25 g $CaCO_3$ (mole Ca fraction = 0.4005), dried at 180°C for 1 hr before weighing, weighed accurately to at least four significant figures, in Type II water and dissolve cautiously with a minimum amount of (1:1) HNO_3. Add 10.0 mL concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.3.9 Chromium solution, stock, 1 mL = 100 ug Cr: Dissolve 0.19 g CrO_3 (mole fraction Cr = 0.5200), weighed accurately to at least four significant figures, in Type II water. When solution is complete, acidify with 10 mL concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.3.10 Cobalt solution, stock, 1 mL = 100 ug Co: Dissolve 0.1000 g of cobalt metal, weighed accurately to at least four significant figures, in a minimum amount of (1:1) HNO_3. Add 10.0 mL (1:1) HCl and dilute to 1,000 mL with Type II water.

5.3.11 Copper solution, stock, 1 mL = 100 ug Cu: Dissolve 0.13 g CuO (mole fraction Cu = 0.7989), weighed accurately to at least four significant figures), in a minimum amount of (1:1) HNO_3. Add 10.0 mL concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.3.12 Iron solution, stock, 1 mL = 100 ug Fe: Dissolve 0.14 g Fe_2O_3 (mole fraction Fe = 0.6994), weighed accurately to at least four significant figures, in a warm mixture of 20 mL (1:1) HCl and 2 mL of concentrated HNO_3. Cool, add an additional 5.0 mL of concentrated HNO_3, and dilute to 1,000 mL with Type II water.

5.3.13 Lead solution, stock, 1 mL = 100 ug Pb: Dissolve 0.16 g $Pb(NO_3)_2$ (mole fraction Pb = 0.6256), weighed accurately to at least four significant figures, in a minimum amount of (1:1) HNO_3. Add 10 mL (1:1) HNO_3 and dilute to 1,000 mL with Type II water.

5.3.14 Magnesium solution, stock, 1 mL = 100 ug Mg: Dissolve 0.17 g MgO (mole fraction Mg = 0.6030), weighed accurately to at least four significant figures, in a minimum amount of (1:1) HNO_3. Add 10.0 mL (1:1) concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.3.15 Manganese solution, stock, 1 mL = 100 ug Mn: Dissolve 0.1000 g of manganese metal, weighed accurately to at least four significant figures, in acid mixture (10 mL concentrated HCl and 1 mL concentrated HNO_3) and dilute to 1,000 mL with Type II water.

5.3.16 Molybdenum solution, stock, 1 mL = 100 ug Mo: Dissolve 0.20 g $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ (mole fraction Mo = 0.5772), weighed accurately to at least four significant figures, in Type II water and dilute to 1,000 mL with Type II water.

5.3.17 Nickel solution, stock, 1 mL = 100 ug Ni: Dissolve 0.1000 g of nickel metal, weighed accurately to at least four significant figures, in 10.0 mL hot concentrated HNO_3, cool, and dilute to 1,000 mL with Type II water.

5.3.18 Potassium solution, stock, 1 mL = 100 ug K: Dissolve 0.19 g KCl (mole fraction K = 0.5244) dried at 110°C, weighed accurately to at least four significant figures, in Type II water and dilute to 1,000 mL.

5.3.19 Selenium solution, stock, 1 mL = 100 ug Se: Do not dry. Dissolve 0.17 g H_2SeO_3 (mole fraction Se = 0.6123), weighed accurately to at least four significant figures, in Type II water and dilute to 1,000 mL.

5.3.20 Silica solution, stock, 1 mL = 100 ug SiO_2: Do not dry. Dissolve 0.47 g $Na_2SiO_3 \cdot 9H_2O$ (mole fraction Si = 0.09884), weighed accurately to at least four significant figures, in Type II water. Add 10.0 mL concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.3.21 Silver solution, stock, 1 mL = 100 ug Ag: Dissolve 0.16 g $AgNO_3$ (mole fraction Ag = 0.6350), weighed accurately to at least four significant figures, in Type II water and 10 mL concentrated HNO_3. Dilute to 1,000 mL with Type II water.

5.3.22 Sodium solution, stock, 1 mL = 100 ug Na: Dissolve 0.25 g NaCl (mole fraction Na = 0.3934), weighed accurately to at least four significant figures, in Type II water. Add 10.0 mL concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.3.23 Thallium solution, stock, 1 mL = 100 ug Tl: Dissolve 0.13 g $TlNO_3$ (mole fraction Tl = 0.7672), weighed accurately to at least four significant figures, in Type II water. Add 10.0 mL concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.3.24 Vanadium solution, stock, 1 mL = 100 ug V: Dissolve 0.23 g NH_4VO_3 (mole fraction V = 0.4356), weighed accurately to at least four significant figures, in a minimum amount of concentrated HNO_3. Heat to increase rate of dissolution. Add 10.0 mL concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.3.25 Zinc solution, stock, 1 mL = 100 ug Zn: Dissolve 0.12 g ZnO (mole fraction Zn = 0.8034), weighed accurately to at least four significant figures, in a minimum amount of dilute HNO_3. Add 10.0 mL concentrated HNO_3 and dilute to 1,000 mL with Type II water.

5.4 Mixed calibration standard solutions: Prepare mixed calibration standard solutions by combining appropriate volumes of the stock solutions in volumetric flasks (see Table 3). Add 2 mL (1:1) HNO_3 and 10 mL of (1:1) HCl and dilute to 100 mL with Type II water (see NOTE, below). Prior to preparing the mixed standards, each stock solution should be analyzed separately to determine possible spectral interference or the presence of impurities. Care should be taken when preparing the mixed standards to ensure that the elements are compatible and stable together. Transfer the mixed standard solutions to FEP fluorocarbon or previously unused polyethylene or polypropylene bottles for storage. Fresh mixed standards should be prepared, as needed, with the realization that concentration can change on aging. Calibration standards must be initially verified using a quality control sample (see Paragraph 5.8) and monitored weekly for stability. Some typical calibration standard combinations are listed in Table 3. All mixtures should then be scanned using a sequential spectrometer to verify the absence of interelement spectral interference in the recommended mixed standard solutions.

NOTE: If the addition of silver to the recommended acid combination results in an initial precipitation, add 15 mL of Type II water and warm the flask until the solution clears. Cool and dilute to 100 mL with Type II water. For this acid combination, the silver concentration should be limited to 2 mg/L. Silver under these conditions is stable in a tap-water matrix for 30 days. Higher concentrations of silver require additional HCl.

TABLE 3. MIXED STANDARD SOLUTIONS

Solution	Elements
I	Be, Cd, Mn, Pb, Se and Zn
II	Ba, Co, Cu, Fe, and V
III	As, Mo, and Si
IV	Al, Ca, Cr, K, Na, and Ni
V	Ag (see Note to Paragraph 5.4), B, Mg, Sb, and Tl

5.5 Two types of blanks are required for the analysis. The calibration blank is used in establishing the analytical curve, and the reagent blank is used to correct for possible contamination resulting from varying amounts of the acids used in the sample processing.

5.5.1 The calibration blank is prepared by diluting 2 mL of (1:1) HNO_3 and 10 mL of (1:1) HCl to 100 mL with Type II water. Prepare a sufficient quantity to flush the system between standards and samples.

5.5.2 The reagent blank must contain all the reagents and in the same volumes as used in the processing of the samples. The reagent blank must be carried through the complete procedure and contain the same acid concentration in the final solution as the sample solution used for analysis.

5.6 The instrument check standard is prepared by the analyst by combining compatible elements at concentrations equivalent to the midpoint of their respective calibration curves (see Paragraph 8.6.2.1 for use).

5.7 The interference check solution is prepared to contain known concentrations of interfering elements that will provide an adequate test of the correction factors. Spike the sample with the elements of interest at approximate concentrations of 10 times the instrumental detection limits. In the absence of measurable analyte, overcorrection could go undetected because a negative value could be reported as zero. If the particular instrument will display overcorrection as a negative number, this spiking procedure will not be necessary.

5.8 The quality control sample should be prepared in the same acid matrix as the calibration standards at 10 times the instrumental detection limits and in accordance with the instructions provided by the supplier.

6.0 SAMPLE COLLECTION, PRESERVATION, AND HANDLING

6.1 See the introductory material in Chapter Three, Inorganic Analytes, Sections 3.1 through 3.3.

7.0 PROCEDURE

7.1 Preliminary treatment of all matrices is always necessary because of the complexity and variability of sample matrices. Solubilization and digestion procedures are presented in Sample Preparation Methods (Methods 3005-3050). The method of standard addition (MSA) (Paragraph 8.5.3) shall be used for the analysis of all EP extracts and sample digests unless either serial dilution or matrix spike addition demonstrates that it is not required. An internal standard may be substituted for the MSA.

7.2 Set up the instrument with proper operating parameters established in Paragraph 4.2. The instrument must be allowed to become thermally stable before beginning (usually requiring at least 30 min of operation prior to calibration).

7.3 Profile and calibrate the instrument according to the instrument manufacturer's recommended procedures, using the typical mixed calibration standard solutions described in Paragraph 5.4. Flush the system with the calibration blank (5.5.1) between each standard (see NOTE, below). (Use the average intensity of multiple exposures for both standardization and sample analysis to reduce random error.)

NOTE: For boron concentrations greater than 500 ug/L, extended flush times of 1 or 2 min may be required.

7.4 Before beginning the sample run, reanalyze the highest mixed calibration standard as if it were a sample. Concentration values obtained should not deviate from the actual values by more than 5% (or the established control limits, whichever is lower). If they do, follow the recommendations of the instrument manufacturer to correct for this condition.

7.5 Flush the system with the calibration blank solution for at least 1 min (Paragraph 5.5.1) before the analysis of each sample (see Note to Paragraph 7.3). Analyze the instrument check standard (5.6) and the calibration blank (5.5.1) after each 10 samples.

7.6 Calculations: If dilutions were performed, the appropriate factors must be applied to sample values. All results should be reported in ug/L with up to three significant figures.

8.0 QUALITY CONTROL

8.1 All quality control data should be maintained and available for easy reference or inspection.

8.2 Dilute and reanalyze samples that are more concentrated than the linear calibration limit or use an alternate, less sensitive line for which quality control data is already established.

8.3 Employ a minimum of one laboratory blank per sample batch to determine if contamination or any memory effects are occurring.

8.4 Analyze one duplicate sample for every 20 samples. A duplicate sample is a sample brought through the whole sample preparation and analytical process.

8.5 It is recommended that whenever a new or unusual sample matrix is encountered, a series of tests be performed prior to reporting concentration data for analyte elements. These tests, as outlined in 8.5.1 through 8.5.3, will ensure the analyst that neither positive nor negative interferences are operating on any of the analyte elements to distort the accuracy of the reported values.

8.5.1 Serial dilution: If the analyte concentration is sufficiently high (minimally, a factor of 10 above the instrumental detection limit after dilution), an analysis of a 1:4 dilution should agree within ±10% of the original determination. If not, a chemical or physical interference effect should be suspected.

8.5.2 Matrix spike addition: An analyte spike added to a portion of a prepared sample, or its dilution, should be recovered to within 75% to 125% of the known value. The spike addition should produce a minimum level of 10 times and a maximum of 100 times the instrumental detection limit. If the spike is not recovered within the specified limits, a matrix effect should be suspected. The use of a standard-addition analysis procedure can usually compensate for this effect.

CAUTION: The standard-addition technique does not detect coincident spectral overlap. If suspected, use of computerized compensation, an alternate wavelength, or comparison with an alternate method is recommended.

8.5.3 Standard addition: The standard-addition technique involves adding known amounts of standard to one or more aliquots of the processed sample solution. This technique compensates for a sample constituent that enhances or depresses the analyte signal, thus producing a different slope from that of the calibration standards. It will not correct for additive interferences which cause a baseline shift. The simplest version of this technique is the single-addition method, in which two identical aliquots of the sample solution, each of Volume V_x, are taken. To the first (labeled A) is added a small volume V_s of a standard analyte solution of concentration c_s. To the second (labeled B) is added the same volume V_s of the solvent. The analytical signals of A and B are measured and corrected for nonanalyte signals. The unknown sample concentration c_x is calculated:

$$c_x = \frac{S_B V_s c_s}{(S_A - S_B)\ V_x}$$

where S_A and S_B are the analytical signals (corrected for the blank) of solutions A and B, respectively. V_s and c_s should be chosen so that S_A is roughly twice S_B on the average. It is best if V_s is made much less than V_x, and thus c_s is much greater than c_x, to avoid excess dilution of the sample matrix. If a separation or concentration step is used, the additions are best made first and carried through the entire procedure. For the results of this technique to be valid, the following limitations must be taken into consideration:

1. The analytical curve must be linear.

2. The chemical form of the analyte added must respond the same way as the analyte in the sample.

3. The interference effect must be constant over the working range of concern.

4. The signal must be corrected for any additive interference.

The absorbance of each solution is determined and then plotted on the vertical axis of a graph, with the concentrations of the known standards plotted on the horizontal axis. When the resulting line is extrapolated back to zero absorbance, the point of interception of the abscissa is the concentration of the unknown. The abscissa on the left of the ordinate is scaled the same as on the right side, but in the opposite direction from the ordinate. An example of a plot so obtained is shown in Figure 1.

8.6 Check the instrument standardization by analyzing appropriate quality control check standards as follows.

8.6.1 Check instrument calibration using a calibration blank and two appropriate standards.

8.6.2 Verify calibration every 10 samples and at the end of the analytical run, using a calibration blank (5.5.1) and a single point check standard (5.6).

8.6.2.1 The results of the check standard are to agree within 10% of the expected value; if not, terminate the analysis, correct the problem, and recalibrate the instrument.

8.6.2.2 The results of the calibration blank are to agree within three standard deviations of the mean blank value. If not, repeat the analysis two more times and average the results. If the average is not within three standard deviations of the background mean, terminate the analysis, correct the problem, recalibrate, and reanalyze the previous 10 samples.

8.6.3 Verify the interelement and background correction factors at the beginning and end of an analytical run or twice during every 8-hour work shift, whichever is more frequent. Do this by analyzing the interference check sample (Paragraph 5.7). Results should be within ±20% of the true value obtained in 8.6.2.1.

8.6.4 Duplicate spiked samples are to be analyzed at a frequency of 20%.

8.6.4.1 The relative percent difference between duplicate determinations is to be calculated as follows:

$$\text{RPD} = \frac{D_1 - D_2}{(D_1 + D_2)/2} \times 100$$

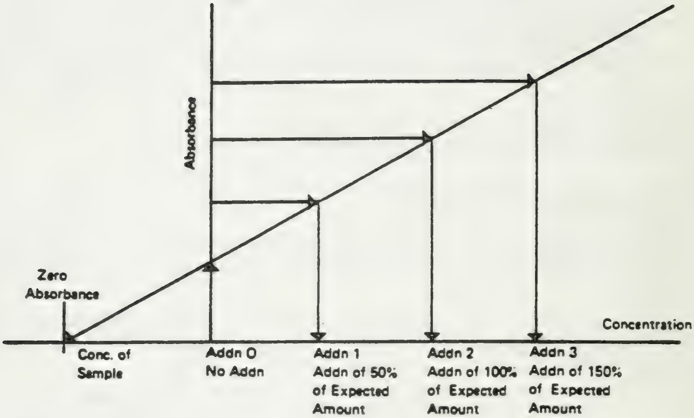


Figure 1. Standard Addition Plot.

where:

RPD = relative percent difference.
D_1 = first sample value.
D_2 = second sample value (duplicate).

(A control limit of ±20% for RPD shall be used for sample values greater than 10 times the instrument detection limit.)

8.6.4.2 The duplicate matrix spike sample recovery is to be within ±20% of the actual value.

8.6.5 The method of standard addition (Paragraph 8.5.3) shall be used for the analysis of all EP extracts.

9.0 METHOD PERFORMANCE

9.1 In an EPA round-robin Phase 1 study, seven laboratories applied the ICP technique to acid-distilled water matrices that had been spiked with various metal concentrates. Table 4 lists the true values, the mean reported values, and the mean percent relative standard deviations.

9.2 In a single laboratory evaluation, seven wastes were analyzed for 22 elements by this method. The mean percent relative standard deviation from triplicate analyses for all elements and wastes was 9±2%. The mean percent recovery of spiked elements for all wastes was 93±6%. Spike levels ranged from 100 ug/L to 100 mg/L. The wastes included sludges and industrial wastewaters.

10.0 REFERENCES

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2. Methods for Chemical Analysis of Water and Wastes, EPA-600/4-82-05, December 1982, Method 200.7.

3. Patel, B.K., Raab, G.A., et al., Report on a Single Laboratory Evaluation of Inductively Coupled Optical Emission Method 6010, EPA Contract No. 68-03-3050, December 1984.

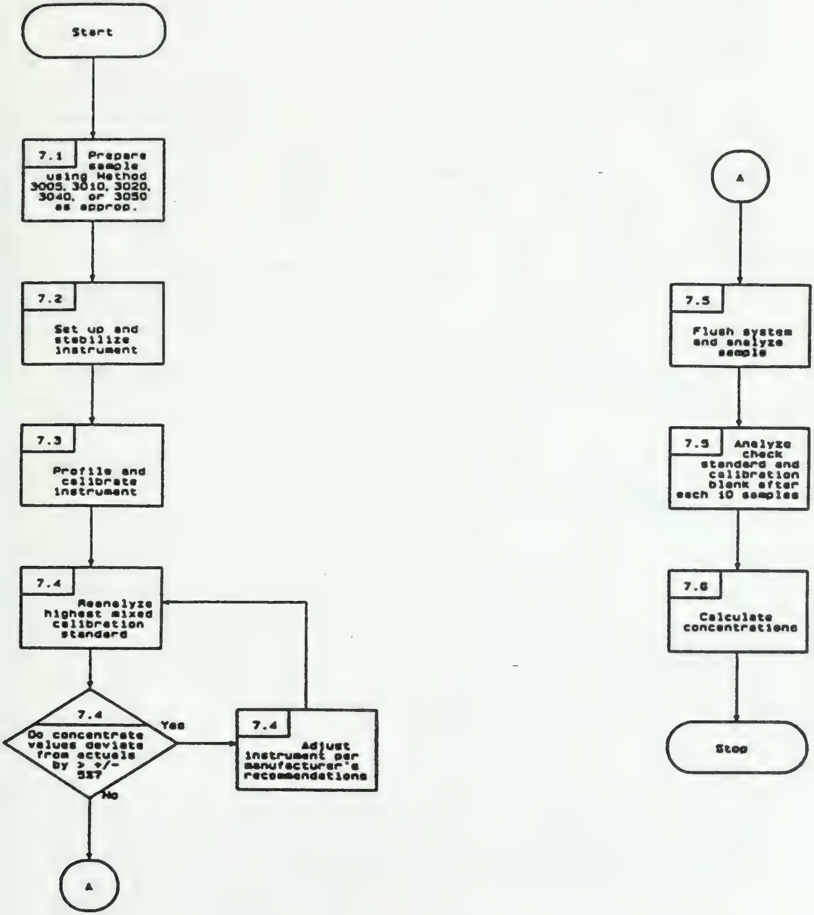
TABLE 4. ICP PRECISION AND ACCURACY DATA[a]

	Sample No. 1			Sample No. 2			Sample No. 3		
Element	True Value (ug/L)	Mean Reported Value (ug/L)	Mean SD[b] (%)	True Value (ug/L)	Mean Reported Value (ug/L)	Mean SD[b] (%)	True Value (ug/L)	Mean Reported Value (ug/L)	Mean SD[b] (%)
Be	750	733	6.2	20	20	9.8	180	176	5.2
Mn	350	345	2.7	15	15	6.7	100	99	3.3
V	750	749	1.8	70	69	2.9	170	169	1.1
As	200	208	7.5	22	19	23	60	63	17
Cr	150	149	3.8	10	10	18	50	50	3.3
Cu	250	235	5.1	11	11	40	70	67	7.9
Fe	600	594	3.0	20	19	15	180	178	6.0
Al	700	696	5.6	60	62	33	160	161	13
Cd	50	48	12	2.5	2.9	16	14	13	16
Co	700	512	10	20	20	4.1	120	108	21
Ni	250	245	5.8	30	28	11	60	55	14
Pb	250	236	16	24	30	32	80	80	14
Zn	200	201	5.6	16	19	45	80	82	9.4
Se[c]	40	32	21.9	6	8.5	42	10	8.5	8.3

[a] Not all elements were analyzed by all laboratories.

[b] SD = standard deviation.

[c] Results for Se are from two laboratories.


Start
7.1 Prepare sample using Method 3005, 3010, 3020, 3040, or 3050 as approp.
7.2 Set up and stabilize instrument
7.3 Profile and calibrate instrument
7.4 Reanalyze highest mixed calibration standard
7.4 Do concentrate values deviate from actuals by > +/- 5%?
Yes
No
7.4 Adjust instrument per manufacturer's recommendations
A
A
7.5 Flush system and analyze sample
7.5 Analyze check standard and calibration blank after each 10 samples
7.6 Calculate concentrations
Stop

ELEMENTS (ICP)

METHOD: 7300
ISSUED: 2/15/84

M.W.: Table 1

OSHA/NIOSH/ACGIH: Table 1

PROPERTIES: Table 1

ELEMENTS:
- aluminum
- arsenic
- beryllium
- cadmium
- calcium
- chromium
- cobalt
- copper
- iron
- lead
- lithium
- magnesium
- manganese
- molybdenum
- nickel
- phosphorus
- platinum
- selenium
- silver
- sodium
- tellurium
- thallium
- tin
- titanium
- tungsten
- vanadium
- yttrium
- zinc
- zirconium

SYNONYMS: vary depending upon the compound.

SAMPLING

SAMPLER: FILTER
(0.8-µm, cellulose ester membrane)

FLOW RATE: 1 to 4 L/min

VOL-MIN: Table 1
-MAX: Table 1

SHIPMENT: routine

SAMPLE STABILITY: stable

BLANKS: 2 to 10 field blanks per set

ACCURACY

RANGE STUDIED: not studied

BIAS: none identified

OVERALL PRECISION (s_r): not evaluated

MEASUREMENT

TECHNIQUE: INDUCTIVELY COUPLED ARGON PLASMA, ATOMIC EMISSION SPECTROSCOPY

ANALYTE: elements above

ASHING REAGENTS: conc. HNO_3, 4 mL; and conc. $HClO_4$, 1 mL
CONDITIONS: room temperature, 30 min; 150 °C to near dryness

FINAL SOLUTION: 4% HNO_3, 1% $HClO_4$, 10 mL

WAVELENGTH: depends upon element; Table 2

BACKGROUND CORRECTION: spectral wavelength shift

CALIBRATION: elements in 4% HNO_3, 1% $HClO_4$

RANGE: 2.5 to 1000 µg per sample [1]

ESTIMATED LOD: 1 µg per sample [1]

PRECISION (s_r): Table 2

APPLICABILITY: The working range of this method is 0.005 to 2.0 mg/m³ for each element in a 500-L air sample. This is simultaneous elemental analysis, not compound specific. Verify that the types of compounds in the samples are soluble with this ashing procedure.

INTERFERENCES: Spectral interferences are the primary interferences encountered in ICP-AES analysis. These are minimized by judicious wavelength selection, interelement correction factors and background correction [1,2].

OTHER METHODS: This method replaces P&CAM 351 [2] for trace elements. Atomic absorption spectroscopy (e.g., Methods 70XX) is an alternate analytical technique for many of these elements.

REAGENTS:

1. Nitric acid, conc.
2. Perchloric acid, conc.*
3. Ashing acid: 4:1 (v/v) HNO_3:$HClO_4$. Mix 4 volumes conc. HNO_3 with 1 volume conc. $HClO_4$.
4. Calibration stock solutions, 1000 µg/mL. Commercially available, or prepared per instrument manufacturer's recommendation (see step 12).
5. Dilution acid, 4% HNO_3, 1% $HClO_4$. Add 50 mL ashing acid to 600 mL water; dilute to 1 L.
6. Argon.
7. Distilled,deionized water.

*See Special Precautions.

EQUIPMENT:

1. Sampler: cellulose ester membrane filter, 0.8-mm pore size, 37-mm diameter; in cassette filter holder.
2. Personal sampling pump, 1 to 4 L/min, with flexible connecting tubing.
3. Inductively coupled plasma-atomic emission spectrometer, equipped as specified by the manufacturer for analysis of elements of interest.
4. Regulator, two-stage, for argon.
5. Beakers, Phillips, 125-mL, or Griffin, 50-mL, with watchglass covers.*
6. Volumetric flasks, 10- and 100- mL.*
7. Assorted volumetric pipets as needed.*
8. Hotplate, surface temperature 150 °C.

*Clean all glassware with conc. nitric acid and rinse thoroughly in distilled water before use.

SPECIAL PRECAUTIONS: Perform all perchloric acid digestions in a perchloric acid hood.

SAMPLING:

1. Calibrate each personal sampling pump with a representative sampler in line.
2. Sample at an accurately known flow rate between 1 and 4 L/min for a total sample size of 200 to 2000 L (see Table 1) for TWA measurements. Do not exceed a filter loading of approximately 2 mg total dust.

SAMPLE PREPARATION:

3. Open the cassette filter holders and transfer the samples and blanks to clean beakers.
4. Add 5 mL ashing acid. Cover with a watchglass. Let stand 30 min at room temperature.
   NOTE: Start a reagent blank at this step.
5. Heat on hotplate (120 °C) until ca. 0.5 mL remains.
   NOTE: Some species of Li, Mn, Mo, Sn, W, and Zr will not be completely solubilized by this procedure. Alternative solubilization techniques for most of these elements can be found elsewhere [2,3,4,5,6,7].
6. Add 2 mL ashing acid and repeat step 5. Repeat this step until the solution is clear.
7. Remove watchglass and rinse into the beaker with distilled water.
8. Increase the temperature to 150 °C and take the sample to dryness.
9. Dissolve the residue in 2 to 3 mL dilution acid.
10. Transfer the solutions quantitatively to 10-mL volumetric flasks.
11. Dilute to volume with dilution acid.

CALIBRATION AND QUALITY CONTROL:

12. Calibrate the spectrometer according to the manufacturers recommendations.
    NOTE: Typically, an acid blank and 10 µg/mL multielement working standards are used. The following multielement combinations are chemically compatible in 4% HNO_3/1% $HClO_4$:
    a. Ag, Ca, Co, Mn, Pb, V, Zn;
    b. Al, Be, Cd, La, Li, Ni, Tl;
    c. As, B, Ba, Mg, Mo, P, Sn;

   - d. Cu, Fe, Na, Pt, Sr, Te, Y;
   - e. Cr, K, Sb, Se, Ti, Zr; and
   - f. Si, W (distilled water only)

13. Analyze a standard for every ten samples.
14. Check recoveries with at least two spiked media blanks per ten samples.

MEASUREMENT:

15. Set spectrometer to conditions specified by manufacturer.
16. Analyze standards and samples.

    NOTE: If the values for the samples are above the range of the standards, dilute the solutions with dilution acid, reanalyze and apply the appropriate dilution factor in the calculations.

CALCULATIONS:

17. Obtain the solution concentrations for the sample, C_s (µg/mL), and the average media blank, C_b (µg/mL), from the instrument.
18. Using the solution volumes of sample, V_s (mL), and media blank, V_b (mL), calculate the concentration, C (mg/m³), of each element in the air volume sampled, V (L):

$$C = \frac{C_sV_s - C_bV_b}{V}, \text{ mg/m}^3.$$

EVALUATION OF METHOD:

Method P&CAM 351 was evaluated in 1981 [1,2]. The precision and recovery data were determined at 2.5 and 1000 µg of each element per sample on spiked filters. The precision and recovery data, instumental detection limits, sensitivity, and analytical wavelengths are listed in Table 2. The values in Table 2 were determined with a Jarrell-Ash Model 1160 ICP operated according to manufacturer's instructions.

REFERENCES:

[1] Hull, R.D. "Multielement Analysis of Industrial Hygiene Samples," NIOSH Internal Report, presented at the American Industrial Hygiene Conference, Portland, Oregon (May 1981).

[2] NIOSH Manual of Analytical Methods, 2nd ed., V. 7, P&CAM 351, U.S. Department of Health and Human Services, Publ. (NIOSH) 82-100 (1981).

[3] Ibid, S341 (Lead).

[4] Ibid, V. 2, S5 (Manganese), U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-B (1977).

[5] Ibid, V. 4, P&CAM 271 (Tungsten), U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 78-175 (1978).

[6] Ibid, V. 5, P&CAM 173 (Metals by Atomic Absorption), U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 79-141 (1979).

[7] Ibid, V. 3, S183 (Tin), S185 (Zirconium), and S376 (Molybdenum), U.S. Department of Health, Education, and Welfare, Publ. (NIOSH) 77-157-C (1977).

METHOD REVISED BY: R. DeLon Hull and Mark Millson, NIOSH/DPSE.

Table 1. Properties and sampling volumes.

Element (Symbol)	Properties: Atomic Weight	Properties: MP, °C	Permissible Exposure Limits, mg/m³ TWA OSHA/NIOSH/ACGIH	Air Volume @ OSHA, L: MIN	Air Volume @ OSHA, L: MAX
Silver (Ag)	107.87	961	0.01/ — / 0.1	250	2000
Aluminum (Al)	26.98	660	— / — / 10.	5 (g)	100 (g)
Arsenic (As)	74.92	817*	0.5/C 0.002/ 0.2	5	2000
Beryllium (Be)	9.01	1278	0.002/ 0.0005/ 0.002	1250	2000
Calcium (Ca)	40.08	842	5 (b)/ — / 2 (b)	5	200
Cadmium (Cd)	112.40	321	0.2/ 0.04/ 0.05	13	2000
Cobalt (Co)	58.93	1495	0.1/ — / 0.1	25	2000
Chromium (Cr)	52.00	1890	1.0 (c)/ 0.025/ 0.5 (c)	5	1000
Copper (Cu)	63.54	1083	1.0/ — / 1.0	5	1000
Iron (Fe)	55.85	1535	10 (b)/ — / 5 (b)	5	100
Lithium (Li)	6.94	179	0.025 (d)/ — / 0.025 (d)	100	2000
Magnesium (Mg)	24.31	651	15 (b)/ — / 10 (b)	5	67
Manganese (Mn)	54.94	1244	C 5/ — / C 5	5	200
Molybdenum (Mo)	95.94	651	15 (e)/ — / 10 (e)	5	67
Sodium (Na)	22.99	98	2 (f)/ C 2 (f)/ C 2 (f)	13	2000
Nickel (Ni)	58.71	1453	1/ 0.015/ 1 (c)	5	1000
Phosphorus (P)	30.97	44	— / — / 0.1	25 (g)	2000 (g)
Lead (Pb)	207.19	328	0.05/ 0.1/ 0.15	50	2000
Platinum (Pt)	195.09	1769	0.002 (a)/ — / 1 (c)	1250	2000
Selenium (Se)	78.96	217	0.2/ — / —	13	2000
Tin (Sn)	118.69	232	2/ — / 2 (c)	5	500
Tellurium (Te)	127.60	450	0.1/ — / 0.1	25	2000
Titanium (Ti)	47.90	1675	— / — / 10 (b)	5	100
Thallium (Tl)	204.37	304	0.1 (a)/ — / 0.1 (a)	25	2000
Vanadium (V)	50.94	1890	C 0.5/ 1 (c)/ 0.05 (V_2O_5)	5	2000
Tungsten (W)	183.85	3410	— / 5 (e)/ 5 (e)	5 (g)	200 (g)
Yttrium (Y)	88.91	1495	1/ — / 1	5	1000
Zinc (Zn)	65.37	419	5 (b)/ 5 (b)/ 5 (b)	5	200
Zirconium (Zr)	91.22	1852	5/ — / 5	5	200

(a) soluble
(b) oxide
(c) metal
(d) hydride
(e) insoluble
(f) hydroxide
(g) at the ACGIH TLV

Table 2. Measurement procedures and data (a).

Element	Wavelength (nm)	Instrumental LOD (ng/mL)	Sensitivity (Intensity/ µg/mL)	Recovery (%)		Precision (s_r) (N = 3)	
				@ 2.5 µg/ filter (b)	@ 1000 µg/ filter	@ 2.5 µg/ filter	@ 1000 µg/ filter
Ag	328.3	26	0.65	111	91	0.02	0.075
Al	308.2	14	0.23	93	100	0.092	0.023
As	193.7	13	0.57	103	99	0.062	0.026
Be	313.0	1.5	1.29	107	90	0.040	0.034
Ca	315.9	10	0.49	99	95	0.036	0.014
Cd	226.5	1.6	0.83	107	99	0.032	0.020
Co	231.2	7.4	0.38	101	95	0.040	0.005
Cr	205.6	1.3	0.50	98	106	0.053	0.016
Cu	324.8	2.1	0.72	98	99	0.036	0.022
Fe	259.9	3.9	0.13	94	97	0.068	0.016
Li	670.8	2.8	0.48	89	95	0.171	0.043
Mg	279.6	24	0.22	105	106	0.084	0.027
Mn	257.6	0.4	0.74	84	93	0.062	0.035
Mo	281.6	7.0	0.18	94	88	0.023	0.049
Na	589.0	10	0.76	(c)	101	(c)	0.045
Ni	231.6	3.4	0.41	105	97	0.027	0.020
P	214.9	22	0.17	(c)	91	(c)	0.056
Pb	220.4	17	0.42	105	95	0.060	0.011
Pt	203.7	15	0.69	106	91	0.041	0.075
Se	190.6	21	0.28	105	97	0.068	0.049
Sn	190.0	64	0.49	74	67	0.33	0.16
Te	214.3	29	0.41	102	94	0.050	0.063
Ti	334.9	1.2	0.55	96	108	0.051	0.029
Tl	190.9	17	0.22	103	95	0.043	0.017
V	310.2	3.2	0.88	99	94	0.043	0.014
W	207.9	13	2.58	35	23	0.053	0.60
Y	371.0	0.8	2.35	99	100	0.015	0.013
Zn	213.9	0.6	0.60	101	94	0.013	0.013
Zr	339.2	1.9	0.88	75	98	0.049	0.008

(a) Values reported were obtained with a Jarrell-Ash Model 1160 ICP; performance may vary with instrument and should be independently verified.

(b) 2.5 µg/filter corresponds to 5 µg/m³ for a 500-L air sample.

(c) Blank levels too high to make accurate determinations

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Applications of Inductively Coupled Plasma Atomic Emission Spectrometry in Occupational Health*

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Inductively coupled plasma atomic emission spectrometry was applied to the determination of metals and metal compounds in samples collected in the workplace for the assessment of occupational exposure of workers. The procedures used to determine a wide range of elements in air sampling filters, dusts, ashes and paints are described. Different hot-plate and microwave-assisted digestion procedures were evaluated. Accuracy, precision and long-term reproducibility of the methods are presented. Quality control and quality assurance approaches used for these types of analyses are discussed and the results are reported.

Keywords: *Air sampling filter; dust and ash; paint; inductively coupled plasma; microwave digestion*

Inductively coupled plasma atomic emission spectrometry (ICP-AES) has been widely applied to the assessment of industrial exposure of workers to metals and metal compounds.[1–4] Before air sampling is carried out to measure such exposure, it is necessary to have some knowledge of the industrial materials and processes that have the potential to cause occupational disease.

Usually, a preliminary plant survey is undertaken, where bulk samples, *e.g.*, dusts, ashes and paints, are collected for the identification of potential health hazards. After the initial survey, detailed air sampling may be carried out. Air samples are collected on membrane filters in designated areas in order to measure actual worker exposure.

The major processes, through which exposure to metals may occur are: abrasive blasting, acid and alkali cleaning of metals, forging, moulding, welding and painting.[5] The transition group of elements are considered to be the major hazards in industry. Other elements of interest in occupational health include As, Sb, Be, Ag and Sn.[5,6] Organic mercury and tin compounds are still used as biocides in paints.

Since the introduction of WHMIS (Workplace Hazardous Materials Information System) in Canada[7] there has been an increase in demand for the identification of major, particularly toxic, components in all types of materials used in the workplace. Paint is a typical request, which has presented many difficulties.

In this paper the procedures used at the occupational health laboratory are presented with the emphasis on quality control (QC) procedures and the long-term reproducibility of data.

Experimental

Equipment

All measurements were carried out on a multi-channel (32 element) Jarrell-Ash 1100 ICP emission spectrometer. A standard Thermo Jarrell-Ash cross-flow nebuliser and torch were used. The instrument was operated at 1.25 kW forward power. The argon flow-rates were as follows: outer, 20; inner, 1.0; and nebuliser, 1.0 l min^{-1}. The sample uptake rate was controlled at 1.6 ml min^{-1} using a peristaltic pump. The plasma viewing was carried out at a height of 16 mm above the load coil. At the time of this study the instrument was operated under PDP-11 DEC computer and SAIL II software, which allowed only two-point calibration.

Comparative results were obtained by neutron activation analysis (NAA) at the SLOWPOKE Reactor Facility, University of Toronto. The reactor was operated at a thermal neutron flux of 2.5×10^{11} n cm^{2} s^{-1}. A 100-s Ge(Li) X-ray spectrometer system was employed for the measurement of Al, Fe, Ca, Mg, As, Ni, V, Sb, Co and Mn. The irradiation time was 16 h in order to cover short and long lifetime isotopes. All elements were measured after appropriate decay times.

Perkin-Elmer 598 and Beckman 4240 infrared spectrophotometers were used for the identification of polymers in paints.

Microwave-assisted digestions of dusts, ashes and paints were carried out in a CEM (Matthews, NC, USA) Model MDS 81D microwave digestion system.

Standards and Chemicals

All stock solutions (1000 mg l^{-1}) were prepared from pure (99.99+%) metals or compounds (Johnson Matthey - Aesar, Toronto, Ontario, Canada). They were verified against National Institute of Standards and Technology (NIST) multi-element standard solutions [NIST Standard Reference Materials (SRMs) 3171, 3172 and 3174] and cross-checked in another Government of Ontario Laboratory.

Multi-element working standards (10 mg l^{-1}) were prepared taking into account the chemical compatibility of each metal, matrix composition, their stability and possible interferences. The accuracy of the 10 mg l^{-1} working standards was verified against diluted NIST multi-element standard solutions and US Environmental Protection Agency (EPA) (ICAP 7 and ICAP 19) reference standard solutions.

Standard reference materials used in this work were NIST SRM 2676b Metals on Filter Media, SRM 1633a Coal Fly Ash and SRM 1579 Powdered Lead-Based Paint.

Air sampling filters used were 0.8 μm pore size, 37 mm diameter mixed cellulose ester membranes (Millipore, Bedford, MA, USA). A random selection of filters from different batches was used for establishing method detection limits and for the preparation of QC samples.

All concentrated acids (nitric, hydrochloric, perchloric and hydrofluoric) used throughout this work were Baker (Phillipsburg, NJ, USA) Instra Analysed grade.

Sample Preparation

Before acid digestion, air sampling filters, dusts and ashes (50–100 mg), paint scrapings (50–100 mg), powdered paint (50–100 mg) and liquid paints (200–400 mg) were placed in 50-ml glass or 100-ml Teflon PFA beakers, or microwave digestion vessels. Dusts, ashes and paint scrapings were ground and well mixed in an agate mortar. Liquid paint was placed on the bottom of the digestion vessel to form a thin layer and the solvents present in the sample were evaporated off at 70 °C.

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* Presented at the 1990 Winter Conference on Plasma Spectrochemistry, St. Petersburg, FL, USA, 8th–13th January, 1990.

The following hot-plate digestions were evaluated.

The digestion of filters for non-volatile elements was performed by refluxing them in covered beakers on a hot-plate for 3 h at 110 °C with 10 ml of aqua regia. The acids were then evaporated to near dryness and the samples were diluted to 20 ml with 2% v/v nitric acid. When non-volatile and volatile (Ag, As, B, Hg, Sb and Sn) elements were required only 3 ml of aqua regia were used and the samples were refluxed as above. After digestion, the samples were not evaporated, but simply diluted to 20 ml with distilled, de-ionised water. Samples submitted for the determination of volatile elements only were digested with 10 ml of 1 + 5 nitric acid, heated on a hot-plate for 3 h at 80 °C and diluted to 20 ml with distilled, de-ionised water.

When acid-soluble non-volatile elements were required in dusts and ashes the samples were digested by refluxing them in covered beakers on a hot-plate for 3 h at 110 °C with 20 ml of aqua regia. After evaporation to near dryness, they were diluted with 10 ml of 2% v/v nitric acid and transferred into 50-ml calibrated flasks. The samples were diluted to volume with 2% v/v nitric acid. For "total" metal concentrations the samples were refluxed in Teflon PFA beakers with 3 ml of hydrofluoric acid at 110 °C for 2 h. Hydrofluoric acid was evaporated to a volume of 0.2–0.3 ml and this decomposition was followed by digestion with aqua regia as detailed above. For the determination of volatile elements the dusts and ashes were refluxed with 20 ml of 1 + 3 nitric acid at 110 °C for 3 h, transferred into calibrated flasks and diluted to 50 ml with distilled, de-ionised water. After any digestion the samples were filtered using a syringe through a 0.45-µm pore size nylon filter when necessary.

Paints and paint scrapings were also digested with aqua regia as described for dusts and ashes. As some of the elements could be bound to organic materials other hot-plate digestion procedures were also evaluated.

(1) Refluxing of samples with 20 ml of concentrated nitric acid in covered beakers at 110 °C for 3 h. After digestion, samples were evaporated to near dryness, diluted with 20 ml of 2% v/v nitric acid and filtered into 50-ml calibrated flasks through Whatman 541 filter-paper. The samples were diluted to volume with the same acid.

(2) Digestion of samples as above with 20 ml of nitric acid - perchloric acid (5 + 1).

(3) Digestion of samples with 10 ml of aqua regia and 10 ml of nitric acid - perchloric acid (5 + 1) added separately and sequentially. The heating conditions and final steps were the same as in previous digestions.

Microwave-assisted digestions for dusts and ashes were carried out using 5 ml of concentrated hydrofluoric acid with 10 ml of aqua regia. Only 10 ml of concentrated nitric acid were used for the digestion of paints. A time of 5 min at 200 W and 5 min at 400 W power for each sample was used. After the digestions, the samples were evaporated to near dryness at 110 °C, then diluted to 50 ml with 2% v/v nitric acid and filtered as above when necessary. When only volatile elements were required the samples were digested as above in the microwave oven using 10 ml of 1 + 3 nitric acid. After cooling, they were transferred into 50-ml calibrated flasks, diluted to volume with distilled, de-ionised water and filtered as above.

The samples were analysed on an ICP atomic emission spectrometer against multi-element inorganic standards. Previously established background correction factors for spectral interferences were applied. These factors were established on simple flat background measurements or two-point slope background measurements when necessary.

Results and Discussion

Metals on Filter Media

The accuracy of the described procedures was evaluated by analysing commercially available standard reference materials and filters received during round robins organised by the Ontario Ministry of Labour and the National Institute for Occupational Safety and Health (NIOSH) (Cincinnati, OH, USA).

The results of the determination of Cd, Mn, Pb and Zn in NIST SRM 2376b Metals on Filter Media are listed in Table 1. Two filters at each level were digested and measured four times, each within a 3-month period.

Good precision and accuracy for the determination of Cd, Pb and Zn on air sampling filters was demonstrated by a consistent proficiency rating on quarterly samples received as part of the Proficiency Analytical Testing Program, rounds 082–098, organised by the National Institute for Occupational Safety and Health (NIOSH-PAT).

A similar programme organised by the quality assurance co-ordinator of the Occupational Health Laboratory, Ontario Ministry of Labour, provided inter-comparison results for Be, Co, Cd, Pb and Zn on filter media (Table 2). As the concentration of metals on spiked filters was varied from one exercise to another the results in this table represent only a small portion of the data collected during the past 4 years.

As filters spiked with other elements, such as Al, Cr or Ni, are not available from the suppliers of reference materials, we produced our own internal QC filters by spiking with multi-element mixtures similar to our standards. These filters are used as part of our daily QC programme. The results listed in Table 3 were obtained over a 3–4-month period and represent the reproducibility of the proposed method. When ten filters at each level were analysed on the same day, the standard deviation obtained was only 10–15% smaller than that obtained over a period of 6 months. These results suggest that, if the ICP spectrometer is held at a constant sensitivity, spiking of the filters is the major source of the imprecision.

Method detection limits for air sampling filters (Table 3) were established by analysing 30 filters from different batches

Table 1. Accuracy of the determination of Cd, Mn, Pb and Zn on filter media (NIST SRM 2676b Metals on Filter Media). Mean of eight measurements on two samples. All values in µg per filter

	Cd		Mn		Pb		Zn	
Filter data	Mean	SD*	Mean	SD*	Mean	SD*	Mean	SD*
Blank: Certified	0.01	—	0.01	—	0.04	—	0.4	0.1
Found	0.009	0.002	0.008	0.003	0.02	0.014	0.31	0.06
Ib: Certified	0.99	0.02	1.88	0.03	7.55	0.1	10.01	0.14
Found	0.96	0.04	1.90	0.04	8.09	0.3	10.13	0.40
IIb: Certified	2.49	0.04	9.41	0.13	14.9	0.2	49.7	0.7
Found	2.39	0.05	9.30	0.15	14.7	0.2	49.0	0.8
IIIb: Certified	10.14	0.12	18.5	0.3	30.4	0.4	99.5	1.2
Found	10.00	0.2	18.5	0.2	30.0	0.5	98.9	1.0

* SD = Standard deviation.

during a 3-month period. These limits were calculated using 3 standard deviations of the element concentrations in the analytical blank (filters, aqua regia and dilution acid). We have found that changes in the detection limits are insignificant provided that the same suppliers and lots of acids and filters are used and the sensitivity of the ICP spectrometer is maintained at a constant level. The relative standard deviation of a series of measurements of the net intensity of our working standards, calculated over a 6-month period (30–100 measurements depending on the element), was between 1 and 2% for all the elements, except phosphorus, for which the relative standard deviation was three times higher.

Dusts and Ashes

The accuracy of the described procedures for dusts and ashes was evaluated by analysing NIST SRM 1633a Coal Fly Ash[8] and by comparing our data with the results obtained from NAA (Table 4).

Table 2. Accuracy of the determination of Be, Cd, Co, Pb and Zn for Ontario Ministry of Labour QC samples during the period 1986–1989. All values in μg per filter

Element	Theoretical value	Amount found		No. of samples
		Mean	SD*	
Be	0.40	0.385	0.002	10
	1.00	0.97	0.045	10
	2.00	1.94	0.06	10
Cd	4.75	4.59	0.11	12
	10.85	10.59	0.21	9
	20.5	20.37	0.21	5
Co	10.0	9.92	0.33	6
	20.0	19.37	0.66	8
	30.0	29.91	0.67	9
Pb	20.5	20.03	0.64	12
	30.5	29.44	0.77	8
	61.5	61.21	2.61	8
Zn	42.0	41.59	0.27	5
	105.0	105.95	2.60	5
	200.0	201.0	0.97	5

* SD = Standard deviation.

Using aqua regia digestion, low (10–20%) recovery was obtained for Al, Fe and Ti, because these elements are probably present as silicates in this material. Use of aqua regia - hydrofluoric acid, as suggested by Bettinelli *et al.*[3] and Infante and Acosta,[4] gave reliable results for most of the elements. However, use of the same mixture and microwave-assisted digestion improved the recovery of Al and Fe. The lower (80%) recovery of As could be attributed to the loss of this element during the evaporation of hydrofluoric acid.

A typical bulk sample collected in the workplace contains a mixture of metal and ordinary dust. Recently, incinerator ashes have also become of interest, particularly from hospitals, and it was necessary to evaluate their content. Therefore, an internal QC sample was prepared to reflect these sample types. About 500 g of metal dust and incinerator ash were mixed, ground and sieved through a 100-mesh sieve at the Ontario Geological Survey Laboratory.

A comparison of different digestion procedures on this material is presented in Table 5. The digestion of this sample using aqua regia gave comparable results to the decomposition with aqua regia - hydrofluoric acid. Therefore, aqua regia digestion is adequate for the dissolution of predominantly metal dust samples. Use of aqua regia - hydrofluoric acid and microwave-assisted digestion improved the recovery of Al and Cr.

The standard deviations listed in Table 5 for the wet digestion procedures described were obtained by the analysis of 10–12 sub-samples of the dust/ash mixture within a 3-month period and represent the between-day reproducibility of the proposed method. The precision is between 15 and 20% for volatile elements such as As and Sb. The digestion procedure not involving the evaporation of acids is recommended for the determination of these elements.

Average method detection limits for dusts and ashes, expressed as μg g^{-1} dry mass (assuming a sample mass of 50 mg and a final volume of 50 ml), are as follows: Ba, Be and Cd, 0.7; Ag, As, Co, Mn and Mo, 2; Bi, Sb, Sn and Zn, 7; Cr, Cu, Mg, Pb and Se, 30; Al, Se and Ti, 55; and B, Ca, Fe, S and P,

Table 3. Reproducibility of the determination of elements on spiked filters within a 3-month period. Mean of determinations in 10–12 samples. All values in μg per filter

Element	Detection limit	Concentration on filter					
		Level 1		Level 2		Level 3	
		Mean	SD*	Mean	SD*	Mean	SD*
Ag	0.1	0.72	0.28	10.33	0.70	—	—
Al	3.0	10.5	0.89	50.8	2.70	191.6	3.7
As	1.0	6.36	1.50	31.2	1.59	115.6	3.4
B	0.6	1.95	0.50	15.0	1.06	53.6	1.60
Ba	0.2	2.14	0.29	10.3	0.21	49.8	1.09
Be	0.006	1.86	0.10	5.76	0.09	25.2	0.30
Ca	3.0	8.74	1.28	46.6	5.06	195.0	13.7
Cd	0.5	1.85	0.12	19.5	0.88	92.3	6.13
Co	0.5	1.79	0.11	19.7	0.99	93.4	5.88
Cr	0.2	2.09	0.24	10.4	0.27	50.1	0.69
Cu	0.5	1.22	0.13	10.5	1.07	47.9	3.23
Fe	2.0	10.4	0.86	51.6	2.29	195.8	3.00
Mg	2.0	4.34	0.52	40.0	1.88	187.5	11.1
Mn	0.05	1.89	0.10	19.7	0.79	94.7	5.71
Mo	0.2	1.90	0.13	9.98	0.14	25.2	0.40
Ni	0.2	1.93	0.15	9.93	0.27	48.7	0.77
Pb	1.0	3.21	0.40	37.3	1.83	189.2	9.72
Sb	0.5	2.27	0.21	9.75	0.65	49.9	1.4
Sn	0.5	2.74	0.39	11.8	0.60	53.0	5.16
Ti	0.2	4.98	0.27	12.6	0.52	27.5	0.60
V	0.1	1.95	0.13	10.5	0.13	24.8	0.36
W	0.5	2.20	0.20	45.0	1.63	—	—
Zn	0.4	2.18	0.11	20.2	0.89	92.8	6.11

* SD = Standard deviation.

Table 4. Comparison of different digestion procedures on NIST SRM 1633a Coal Fly Ash. Mean of determinations in six sub-samples

Element	Certified range[8]	Aqua regia		Aqua regia + HF		Aqua regia + HF (microwave)		Direct NAA	
		Mean	SD*	Mean	SD*	Mean	SD*	Mean	SD*
Al†	14.0–14.8	2.50	0.36	13.0	0.48	14.2	0.50	15.0	0.60
Fe†	9.50–9.60	6.00	0.28	8.95	0.32	9.44	0.30	9.55	0.21
Ca†	1.08–1.22	0.82	0.16	0.98	0.16	1.10	0.18	1.10	0.20
Ti†	0.78–0.90	0.18	0.06	0.76	0.10	0.79	0.09	0.74	0.09
Mg†	0.38–0.60	0.35	0.03	0.33	0.04	0.45	0.04	0.30	0.20
S†	(0.18)	0.21	0.03	0.21	0.03	0.20	0.02	NA§	
P†	0.17–0.20	0.14	0.04	0.20	0.04	0.21	0.03	NA§	
Ba†	0.106–0.176	0.09	0.02	0.11	0.03	0.14	0.02	0.17	0.03
V¶	280–360	230	12	280	13	290	12	NA§	
Zn¶	220–250	180	20	230	22	225	26	300	40
Mn¶	170–270	200	21	180	23	205	18	200	20
Cr¶	180–200	100	15	180	16	182	15	210	10
As¶	145–155	140	12	102	12	110	13	150	15
Ni¶	120–190	90	9	154	11	158	10	70	10
Pb¶	70–80	100	12	88	10	77	13	NA§	
Co¶	(46)	40	5	52	7	56	8	44	2
Be¶	(12)	10	1	20	2	20	3	NA§	

* SD = Standard deviation.
† Values for Al, Fe, Ca, Ti, Mg, S, P and Ba in % m/m.
‡ Detection limit for NAA technique.
§ NA = Data not reported from NAA.
¶ Values for V, Zn, Mn, Cr, As, Ni, Pb, Co and Be in μg g^{-1}.

Table 5. Comparison of different digestion procedures on a mixed metal dust/ash internal QC sample. Mean of determinations in ten sub-samples

Element	Aqua regia		Aqua regia + HF		Aqua regia + HF (microwave)		Direct NAA	
	Mean	SD*	Mean	SD*	Mean	SD*	Mean	SD*
Al†	11.7	0.23	11.5	0.45	14.5	0.52	15.3	0.60
Fe†	4.55	0.22	4.42	0.40	5.10	0.35	5.6	0.2
Ca†	4.50	0.07	4.15	0.22	5.20	0.35	5.6	0.3
Mg†	1.40	0.03	1.30	0.10	1.50	0.30	1.6	0.4
S†	1.05	0.04	1.06	0.05	1.04	0.04	NA‡	
Ba†	0.76	0.03	0.81	0.04	0.79	0.03	0.82	0.04
Ti†	0.42	0.04	1.68	0.11	1.80	0.09	1.9	0.1
P†	0.23	0.04	0.25	0.06	0.30	0.04	NA‡	
Cu†	0.28	0.03	0.29	0.03	0.30	0.02	NA‡	
Zn†	0.26	0.01	0.30	0.02	0.30	0.02	0.40	0.04
Mn§	930	69	1000	80	1100	75	1200	100
Pb§	740	104	890	120	800	84	NA‡	
Cr§	400	130	760	72	910	70	980	40
Sn§	240	40	390	60	300	32	NA‡	
Ni§	220	42	210	38	180	25	150	20
As§	160	13	156	22	150	30	170	10
Mo§	110	17	110	18	130	15	NA‡	
Sb§	35	10	70	12	65	5	54	2

* SD = Standard deviation.
† Values for Al, Fe, Ca, Mg, S, Ba, Ti, P, Cu and Zn in % m/m.
‡ Data not available from NAA.
§ Values for Mn, Pb, Cr, Sn, Ni, As, Mo and Sb in μg g^{-1}.

100 μg g^{-1}. They were established as 3 standard deviations of 12 measurements of element concentrations in aqua regia - hydrofluoric acid taken on different days.

Paints

The term "paint" covers a broad range of products from conventional paints to varnishes, enamels and lacquers. Conventional paint is basically an inorganic pigment dispersed in a matrix consisting of a binder and a solvent with selected fillers and additives.[5] The binder may be a naturally occurring oil or resin, *e.g.*, cellulose, or a synthetic material such as poly(vinyl acetate), polyurethane, polyesters or polystyrene. Calcium or barium carbonate, mica or talc are used as general fillers. Inorganic pigments may contain elements such as Pb, Cr, Al, Sb and Co. Organic tin compounds, mainly tributyltin, are still used in some paints. These elements present the major hazard during the industrial use of paints. A mixture of several solvents, as shown in Table 6, is used to keep the paint in a liquid form.

Information on the determination of elements in paints by ICP-AES is very limited. Most of these applications have been concerned with the determination of Pb in paints and paint scrapings by atomic absorption spectrometry.[9,10] At present, direct current plasma (DCP) spectrometry is the recommended method for the analysis of paints.[6] However, DCP spectrometers are not always available as is the case in this laboratory.

A variety of digestion procedures were investigated in order to determine optimum conditions for the determination of toxic elements in liquid and powdered paints and paint scrapings by ICP-AES. These procedures were evaluated by analysing several industrial and domestic paints having major differences in their chemical compositions.

The accuracy of the described procedures was established by analysing NIST SRM 1579 Powdered Lead-Based Paint. The certified concentration of Pb in this material is 11.80 ± 0.04%. The pooled mean from the determination of Pb in 15 sub-samples using all of the previously described procedures was 11.78 ± 0.33%. No significant difference in the results was obtained by different digestion methods or by different analysts. It was not possible to establish recoveries for other elements as no other data are available for this material and no other paint SRM is known to us.

For some of the paints, much lower recoveries of Pb and other elements were obtained after digestion with aqua regia compared with other nitric acid based digestions, probably because these elements are bound to the organic matrix.

For isophthalic acid polyester based paint (Table 7) recoveries of approximately 50% for Pb and some other elements were obtained after digestion with aqua regia compared with nitric acid alone or nitric acid - perchloric acid digestions. An even better example is shown for epoxy-based auto spray (Table 8), where the recovery of Pb was 17% and of other elements approximately 30% after aqua regia digestion. On the other hand, comparable results for all the elements in paint scrapings were obtained using aqua regia or microwave-assisted digestion with nitric acid (Table 9).

Use of concentrated nitric acid alone in open vessels gave complete digestion only for cellulose and isophthalic acid based paints (Table 7). Digestion of these paints at 110 °C takes only 30 min; hence microwave-assisted digestion of these types of paints is not necessary.

For most paints and paint scrapings the efficiency of the acid extraction of the determined elements became higher when digestion with nitric acid - perchloric acid (5 + 1) was used. The greater oxidising power of this mixture appears to be important for the breakdown of the organic components of the matrix. Various ratios of these acids were investigated with no significant increase in the recovery of the elements with increasing amounts of perchloric acid.

In a routine laboratory it is more convenient, when possible, to have a single digestion procedure for the same types of material. As some paints gave higher results with an aqua regia digestion and others with a nitric acid - perchloric acid digestion, it was decided to use equal amounts of these two mixtures as our routine recommended procedure for open-vessel hot-plate digestion of paints and paint scrapings. The dissolving properties of this mixture are most probably enhanced as a result of the oxidation of Cl^- to Cl^0 and formation of chlorine trioxide. Even when the polymers were not totally dissolved they were dispersed as small particles allowing for the better penetration of the acids.

The highest "recovery" and the best repeatability for several elements, *e.g.*, Pb and Cr (Table 8), and Pb, Zn, Ca and Mg (Table 9), in paints were obtained when nitric acid microwave-assisted digestion was used. The best illustration of this effect is the determination of Pb in orange paint scrapings (Table 9). For this sample the concentration obtained after microwave-assisted digestion is 25% higher than that obtained after decomposition with the other acid mixtures.

Another major advantage of microwave-assisted digestion of paints is that it eliminates the necessity of using perchloric acid. This could be important for some ICP nebulisers, which are expected to be affected by perchlorates.[11] We have investigated this effect on our nebuliser by comparing the short-term precision of the net intensity of our 10 mg l^{-1} working standards diluted with 2% v/v nitric acid and 2% v/v perchloric acid. The sensitivities for many elements determined in dilute perchloric acid were found to be 1–2% higher than for the standards diluted with nitric acid. Short-term precision was also 2–3% better for standards diluted with perchloric acid rather than with nitric acid. However, taking into account the dilution errors and the drift of the instrument,

Table 6. Composition of a paint used in the aircraft industry

Component	Compound	Element	Concentration/ µg g^{-1}*
Binder	Epoxy polyester resin with vinyl acetate	Cr	38000
Filler: General	Calcium carbonate	Pb	1400
Extender	Barium carbonate	Ba	640
	Sulphonamide	Fe	180
Pigment	Lead chromate	S	200
	Zinc oxide	Al	170
	Strontium nitrate	Ca	150
	Aluminium chloride	Zn	45
	Iron chromate	Sn	40
Solvent	Ethyl methyl ketone		
	Isobutyl methyl ketone		
	Ethyl acetate		
	Butyl acetate		
	Cyclohexane		
	Toluene		
	Xylene		
Biocide	Organotin compounds		

* Average data of determinations in 20 sub-samples of wet paint by different digestion procedures.

Table 7. Comparison of different digestion procedures on isophthalic acid polyester based industrial paint (yellow). Mean of determinations in six sub-samples of wet paint

	Aqua regia		HNO_3		HNO_3 - $HClO_4$ (5 + 1)		HNO_3 (microwave)	
Element	Mean	SD*	Mean	SD*	Mean	SD*	Mean	SD*
Pb†	1.85	0.37	3.30	0.45	3.50	0.47	3.52	0.32
Cr†	0.44	0.040	0.61	0.033	0.60	0.035	0.62	0.030
Ba‡	800	68	1600	72	1564	74	1580	65
S‡	840	70	1410	88	1340	94	1370	75
Al‡	330	31	500	39	532	46	540	40
Co‡	190	20	260	18	270	13	275	17
Ti‡	100	38	200	29	186	33	190	27
Sb‡	44	6	58	6	53	5	54	5

* SD = Standard deviation.
† Values for Pb and Cr in % m/m.
‡ Values for Ba, S, Al, Co, Ti and Sb in µg g^{-1}.

Table 8. Comparison of different digestion procedures on epoxy-based paint (yellow auto spray). Mean of determinations in six sub-samples of wet paint

	Aqua regia		HNO_3		HNO_3 - $HClO_4$ (5 + 1)		Aqua regia + HNO_3 - $HClO_4$ (5 + 1)		HNO_3 (microwave)	
Element	Mean	SD*	Mean	SD*	Mean	SD*	Mean	SD*	Mean	SD*
Pb†	2.03	0.21	10.2	0.42	12.2	0.45	12.8	0.48	14.1	0.40
Cr†	0.98	0.09	1.82	0.25	2.67	0.20	2.77	0.25	2.99	0.18
Al†	0.11	0.020	0.31	0.016	0.38	0.025	0.31	0.028	0.35	0.027
Fe†	0.09	0.015	0.13	0.015	0.18	0.019	0.16	0.027	0.17	0.025
Ca‡	270	45	700	52	740	51	690	52	770	55
Ba‡	90	20	500	45	550	47	600	55	630	48
Co‡	150	28	338	32	400	27	380	30	400	31
As‡	60	20	300	23	390	32	330	31	310	29
Ti‡	80	25	280	33	280	34	240	36	200	26
Sb‡	30	10	220	18	250	24	230	22	200	18

* SD = Standard deviation.
† Values for Pb, Cr, Al and Fe in % m/m.
‡ Values for Ca, Ba, Co, As, Ti and Sb in µg g^{-1}.

Table 9. Comparison of different digestion procedures on paint scrapings. Mean of determinations in six sub-samples

	Aqua regia		HNO_3		HNO_3 - $HClO_4$ (5 + 1)		Aqua regia + HNO_3 - $HClO_4$ (5 + 1)		HNO_3 (microwave)	
Element	Mean	SD*	Mean	SD*	Mean	SD*	Mean	SD*	Mean	SD*
Sample 1. Orange scrapings (% m/m)—										
Pb	21.8	0.41	20.9	0.47	20.7	0.52	19.1	0.40	27.8	0.48
Zn	1.26	0.042	1.44	0.046	1.57	0.048	1.90	0.034	2.84	0.037
Ca	0.88	0.067	0.95	0.055	1.02	0.085	0.82	0.074	1.42	0.066
Mg	0.65	0.016	0.54	0.015	0.49	0.017	0.48	0.014	0.75	0.020
Al	0.37	0.026	0.39	0.017	0.44	0.025	0.42	0.027	0.55	0.028
Ti	0.19	0.016	0.21	0.014	0.20	0.016	0.18	0.017	0.25	0.018
Fe	0.22	0.010	0.20	0.011	0.14	0.009	0.18	0.008	0.23	0.006
Sample 2. Red scrapings—										
Fe†	15.6	0.55	13.0	0.58	12.9	0.60	13.6	0.53	12.9	0.42
Mg†	0.95	0.054	0.96	0.047	1.00	0.051	0.78	0.055	0.69	0.042
Ca†	0.53	0.036	0.66	0.029	0.50	0.038	0.81	0.039	0.78	0.038
Pb†	0.59	0.061	0.48	0.057	0.50	0.059	0.47	0.085	0.39	0.072
Al‡	90	21	110	22	82	23	150	26	217	21
Cr‡	60	9	67	8	80	6	64	7	58	8
Zn‡	39	10	52	8	44	9	55	11	52	9
Mn‡	40	3	50	3	49	2	49	3	52	3
Co‡	25	3	28	3	30	3	23	2	24	2

* SD = Standard deviation.
† Values for Fe, Mg, Ca and Pb in % m/m.
‡ Values for Al, Cr, Zn, Mn and Co in µg g^{-1}.

it can be concluded that the Thermo Jarrell-Ash cross-flow nebuliser is not significantly affected by low levels of perchlorates.

For our internal quality assurance/quality control (QA/QC) programme we chose powdered paint, which was obtained from a local industry. Unfortunately, only three elements are present in sufficiently high concentrations in this paint for it to be useful for QC purposes. This powdered paint sample was analysed 15 times over a 3-month period using the recommended digestion procedure with equal volumes of aqua regia and nitric acid - perchloric acid. The results of these analyses enabled the long-term reproducibility of this procedure to be evaluated. The mean and standard deviation of each element are as follows: Fe, 4.50 ± 0.20; Ba, 2.00 ± 0.20; and Al, 0.100 ± 0.009%. In cases of suspected lead exposure, NIST SRM 1579 Powdered Lead-Based Paint was used as the external QC material.

The average method detection limits of elements in paints were established as 3 standard deviations of 12 determinations of the elements using aqua regia - nitric acid - perchloric acid (5 + 1) and also nitric acid. The elements were measured on different days. The detection limits are comparable to those established for dusts and ashes.

Conclusions

Inductively coupled plasma atomic emission spectrometry has proved to be an effective analytical technique both for surveys and as a specific quantitative analytical tool for evaluating the industrial exposure of workers to metals. Current ICP instrumentation properly used can generate fast and accurate measurements. However, in routine laboratory operation, sample preparation can still be the longest and often the most difficult step of the analytical procedure.

When microwave-assisted digestion is available, we strongly recommend its use for the following reasons: (1) speed of the decomposition, (2) better recovery may be obtained than with hot-plate open-vessel digestions, (3) elimination of potential interferences caused by other acids and (4) elimination of possible glassware contamination.[12–15] Total time of hot-plate digestion of dusts, ashes or paints, including evaporation of acids, is about 6 h, whereas the same procedure using microwave-assisted digestion takes only 1 h.

A closed-vessel microwave-assisted digestion system may not be advantageous for the handling of large numbers of samples. In the routine analysis of air sampling filters the advantages of using the present 12 vessel closed system are limited because of the large number (40–60) of air sampling filters to be analysed at any one time. However, this technique can be easily applied to the digestion of dusts and ashes and other bulk materials using aqua regia - hydrofluoric acid.

Based on our results, we consider that the proposed digestion procedure, using a mixture of aqua regia and nitric acid - perchloric acid, is a good compromise for the decomposition of pigments and fillers in a wide range of industrial and domestic paints and paint scrapings. The procedure is rapid and simple and can be routinely used for all the paints evaluated. Microwave-assisted digestion with nitric acid guarantees good efficiency of extraction of elements from paints and does not decompose the polymers. This may be beneficial for the elimination of possible matrix effects.

Our work highlights the need for the introduction of a powdered paint SRM certified for a large variety of elements. Our QC programme has also highlighted the lack of availability of low-cost industrial hygiene reference materials.

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APPENDIX B

CONCENTRATION OF CHEMICAL SPECIES MEASURED IN WOODSMOKE EMISSIONS AND RATIOS TO BEEP

APPENDIX B-1

CONCENTRATION OF CHEMICAL SPECIES MEASURED IN WOODSMOKE EMISSIONS FOR EACH INDIVIDUAL TEST

Stove Type A

	Date Sampled		June 25	June 28	July 3	Aug. 30	Sept. 3	June 17	Sept. 4	Sept. 10
	Stove Type		A	A	A	A	A	A	A	A
	Wood Type		Pine	Pine	Pine	Birch	Birch	Maple	Maple	Maple
	Volume (Dscm)		0.664	0.857	0.415	0.706	0.917	1.025	0.735	0.872
	Symbol	Spec. #	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)
ORGANICS										
Fluorene	FLOR	222	117.3	1.6	192.8	64.2	70.1	31.7	370.2	199.8
Dibenzothiophene	DIBE	221	1.4	0.0	1.5	0.0	0.0	0.4	11.6	0.0
Phenanthrene	PHEN	231	5.4	10.7	484.5	24.8	206.0	231.5	359.3	190.6
Anthracene	ANTH	211	302.8	0.0	0.0	55.6	63.2	36.4	0.0	59.1
Acridine	ACRI	210	0.0	2.3	0.0	0.0	0.0	0.0	601.1	0.0
Carbazole	CARB	218	2.7	3.9	2.7	1.4	0.6	1.4	12.5	4.5
Fluoranthene	FLUO	223	189.5	3.4	536.6	176.6	139.9	139.1	327.2	268.7
Pyrene	PYRE	232	537.6	0.4	413.7	143.3	138.9	99.4	738.8	324.4
Retene	RETE	233	125.7	0.0	2.1	11.6	0.3	0.4	15.4	0.0
Tetracosane	TETR	234	13.6	9.3	22.2	0.0	0.0	1.8	1.7	0.0
Pentacosane	TRIA	235	21.4	10.0	31.6	0.0	0.0	5.9	0.0	0.0
Chrysene	CHRY	219	300.5	3.0	142.0	37.5	33.4	22.7	608.9	132.6
1,2-Benzanthracene	BZA		385.6	2.6	186.7	47.1	43.0	28.0	894.5	193.1
Hexacosane	HEXA	225	18.4	126.2	25.4	8.5	0.0	1.7	0.0	4.1
Octacosane	OCTA	228	12.3	4.3	25.8	4.3	0.0	3.7	0.0	4.4
Benzo(b+k)Fluoranthene	BEBF	213	904.2	13.9	379.0	86.3	78.5	61.1	730.6	289.1
Nonacosane	NONA	227	12.2	7.7	24.0	4.1	0.0	2.5	0.0	4.1
Benzo(e)Pyrene	BEEP	215	185.5	2.2	65.1	22.6	18.6	8.9	760.6	87.0
Benzo(a)Pyrene	BAP	212	273.1	3.9	89.6	30.5	27.9	14.3	738.0	129.4
Perylene	PERY	230	60.1	0.0	18.0	9.6	9.5	2.9	156.3	30.1
Indeno(1,2,3-c,d)Pyrene	INDE	226	131.6	6.1	90.6	32.8	31.3	16.9	949.9	110.5
Dibenzo(a,h)Anthracene	DIAA	220	22.1	2.7	13.8	6.1	4.5	1.3	207.9	27.3
Benzo(ghi)Perylene	BEGP	216	74.9	1.2	97.0	45.6	51.6	12.7	1280.4	141.6
INORGANICS										
Silver	Ag	47	0.3	0.5		nd	nd		nd	nd
Aluminum	Al	13	nd	nd		nd	2.9		1146.5	312.7
Bismuth	Bi	83	nd	nd		nd	nd		nd	nd
Boron	B	5	nd	nd		nd	nd		890.2	163.2
Barium	Ba	56	nd	nd		nd	nd		1937.4	463.3
Beryllium	Be	4	nd	nd		nd	nd		0.7	nd
Cadmium	Cd	48	3.7	3.2		7.6	15.3		16.4	13.5
Calcium	Ca	20	nd	nd		nd	nd		274.4	31.7
Cobalt	Co	27	nd	nd		nd	nd		nd	nd
Chromium	Cr	24	0.5	0.6		nd	0.6		1.3	1.1
Copper	Cu	29	3.5	1.7		0.7	6.1		1.2	1.1
Iron	Fe	26	nd	nd		nd	17.9		13.1	10.3
Potassium	K	19	802.2	49.8		655.3	918.9		3024.0	3007.6
Manganese	Mn	25	11.5	18.2		2.6	9.2		5.5	5.8
Molybdenum	Mo	42	nd	nd		nd	nd		nd	nd
Nickel	Ni	28	nd	nd		nd	2.0		5.2	1.0
Lead	Pb	82	4.5	3.3		27.2	70.0		31.8	42.0
Tin	Sn	50	nd	nd		nd	nd		nd	nd
Titanium	Ti	22	nd	nd		nd	nd		nd	nd
Vanadium	V	23	nd	nd		nd	nd		nd	nd
Zinc	Zn	30	nd	nd		nd	2319.5		1669.4	1154.8
COMBUSTION GASES										
Carbon Monoxide (ppm)	CO		57	90	91	400	500	55	18600	1500
Carbon Dioxide (%)	CO2		5.5	9	6.5	1.5	11.2	7.7	19.4	7.5

NA: Not Available; nd: Non Detectable = 0

Stove Type B

	Date Sampled		Aug. 7	Aug. 12	July 30	Aug. 1	July 22	July 24
	Stove Type		B	B	B	B	B	B
	Wood Type		Pine	Pine	Birch	Birch	Maple	Maple
	Volume (Dscm)		1.02	0.9	1.124	0.977	0.771	0.861
	Symbol	Spec. #	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)
ORGANICS								
Fluorene	FLOR	222	184.6	176.9	328.9	258.1	263.4	514.9
Dibenzothiophene	DIBE	221	0.0	0.0	5.1	0.0	1.0	5.0
Phenanthrene	PHEN	231	112.9	60.4	595.9	57.9	331.3	230.2
Anthracene	ANTH	211	19.9	0.0	100.6	0.0	32.1	0.0
Acridine	ACRI	210	0.0	0.0	0.0	0.0	0.0	0.0
Carbazole	CARB	218	0.7	0.6	6.1	0.8	4.5	16.1
Fluoranthene	FLUO	223	139.5	138.8	422.2	144.2	460.7	157.5
Pyrene	PYRE	232	147.5	121.2	545.0	345.4	247.9	592.1
Retene	RETE	233	467.2	57.1	17.1	40.6	0.0	0.0
Tetracosane	TETR	234	0.0	0.0	1.6	2.5	2.9	4.9
Pentacosane	TRIA	235	1.1	2.1	46.7	1.2	7.4	7.3
Chrysene	CHRY	219	101.3	123.1	153.2	178.1	112.6	312.2
1,2-Benzanthracene	BZA		131.6	166.9	205.4	243.8	153.2	343.1
Hexacosane	HEXA	225	0.0	0.0	7.4	0.6	4.6	12.1
Octacosane	OCTA	228	2.0	2.4	7.3	2.3	3.0	3.4
Benzo(b+k)Fluoranthene	BEBF	213	419.9	401.4	431.4	232.3	409.7	704.4
Nonacosane	NONA	227	0.7	1.0	6.3	1.4	4.0	3.1
Benzo(e)Pyrene	BEEP	215	63.4	61.4	84.5	89.9	101.9	108.9
Benzo(a)Pyrene	BAP	212	117.9	89.2	163.3	156.6	143.1	256.9
Perylene	PERY	230	25.3	20.7	33.9	34.0	29.5	47.0
Indeno(1,2,3-c,d)Pyrene	INDE	226	65.6	65.7	76.5	90.9	74.6	105.4
Dibenzo(a,h)Anthracene	DIAA	220	28.6	30.2	25.1	36.6	28.6	36.0
Benzo(ghi)Perylene	BEGP	216	71.2	75.6	95.5	104.3	81.3	126.9
INORGANICS								
Silver	Ag	47	1.4	0.4	nd	nd	0.5	nd
Aluminum	Al	13	nd	nd	nd	nd	nd	nd
Bismuth	Bi	83	nd	nd	nd	nd	nd	nd
Boron	B	5	nd	555.9	178.2	145.7	nd	295.4
Barium	Ba	56	nd	515.6	nd	nd	nd	51.1
Beryllium	Be	4	nd	nd	nd	nd	nd	nd
Cadmium	Cd	48	2.0	3.2	6.3	14.6	2.8	6.2
Calcium	Ca	20	nd	37.4	nd	7.8	nd	nd
Cobalt	Co	27	5.1	4.2	3.2	5.9	nd	2.8
Chromium	Cr	24	0.1	0.8	0.3	0.5	0.2	0.9
Copper	Cu	29	1.0	1.6	0.7	2.7	1.8	1.8
Iron	Fe	26	4.7	7.1	6.2	13.9	nd	10.7
Potassium	K	19	81.0	1714.1	144.7	4056.0	5658.5	3859.1
Manganese	Mn	25	19.8	8.9	10.0	18.9	1.9	3.5
Molybdenum	Mo	42	nd	nd	nd	nd	nd	nd
Nickel	Ni	28	nd	nd	nd	nd	nd	nd
Lead	Pb	82	3.5	7.3	14.6	31.7	5.4	24.4
Tin	Sn	50	nd	nd	nd	nd	nd	nd
Titanium	Ti	22	nd	nd	nd	nd	nd	nd
Vanadium	V	23	nd	nd	nd	nd	nd	nd
Zinc	Zn	30	nd	607.8	351.4	1092.1	nd	303.1
COMBUSTION GASES								
Carbon Monoxide (ppm)	CO		3300	750	750	1100	2500	7500
Carbon Dioxide (%)	CO2		7.5	2.5	3.5	0.2	4.5	6

NA: Not Available; nd: Non Detectable = 0

Stove Type C

		Date Sampled	Aug. 27	Aug. 29	Aug. 23	Aug. 26	Aug. 20	Sept. 11
		Stove Type	C	C	C	C	C	C
		Wood Type	Pine	Pine	Birch	Birch	Maple	Maple
		Volume (Dscm)	0.851	0.43	0.893	0.906	0.843	1.558
	Symbol	Spec. #	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)	Conc (µg/m3)
ORGANICS								
Fluorene	FLOR	222	37.9	962.6	35.6	137.5	309.7	217.6
Dibenzothiophene	DIBE	221	0.0	36.6	0.0	0.0	4.9	2.4
Phenanthrene	PHEN	231	0.0	871.3	95.6	217.2	124.0	138.9
Anthracene	ANTH	211	40.2	1131.8	0.0	58.8	327.9	136.9
Acridine	ACRI	210	0.0	456.5	0.0	0.0	0.0	168.9
Carbazole	CARB	218	0.4	196.4	2.3	3.5	0.0	15.1
Fluoranthene	FLUO	223	107.6	1252.9	195.1	215.0	342.9	172.0
Pyrene	PYRE	232	68.6	1986.0	183.6	317.5	367.6	165.3
Retene	RETE	233	51.1	2703.7	15.7	4.6	12.2	33.3
Tetracosane	TETR	234	0.0	15.7	0.0	0.0	7.9	0.0
Pentacosane	TRIA	235	0.0	0.0	8.9	0.0	0.0	0.0
Chrysene	CHRY	219	41.1	1557.2	104.2	139.5	395.6	296.1
1,2-Benzanthracene	BZA		54.1	2002.4	169.3	203.8	56.5	437.3
Hexacosane	HEXA	225	0.0	0.0	8.1	0.0	7.7	19.2
Octacosane	OCTA	228	0.0	0.0	4.7	0.0	0.0	0.0
Benzo(b+k)Fluoranthene	BEBF	213	49.1	1014.5	266.1	315.4	209.8	427.7
Nonacosane	NONA	227	3.6	0.0	1.2	0.0	0.0	0.4
Benzo(e)Pyrene	BEEP	215	10.3	571.6	81.4	111.3	309.1	46.5
Benzo(a)Pyrene	BAP	212	3.4	951.5	174.2	155.0	81.9	184.2
Perylene	PERY	230	2.1	147.7	37.8	35.5	114.4	27.2
Indeno(1,2,3-c,d)Pyrene	INDE	226	16.3	543.0	118.1	124.5	273.5	411.4
Dibenzo(a,h)Anthracene	DIAA	220	2.8	223.9	26.9	29.7	62.9	91.7
Benzo(ghi)Perylene	BEGP	216	9.4	473.7	151.9	164.1	329.1	596.1
INORGANICS								
Silver	Ag	47	nd	nd	nd	nd	nd	nd
Aluminum	Al	13	912.7	nd	2132.9	nd	nd	nd
Bismuth	Bi	83	nd	nd	nd	nd	nd	nd
Boron	B	5	1332.9	nd	2479.7	nd	5.1	nd
Barium	Ba	56	1649.8	nd	4013.4	nd	nd	nd
Beryllium	Be	4	0.6	nd	1.0	nd	nd	nd
Cadmium	Cd	48	6.0	2.7	19.7	8.2	2.5	2.3
Calcium	Ca	20	453.2	nd	nd	425.7	nd	nd
Cobalt	Co	27	1.6	2.3	3.8	2.2	3.3	nd
Chromium	Cr	24	0.6	nd	0.8	nd	0.2	nd
Copper	Cu	29	1.4	nd	3.9	5.8	8.4	1.0
Iron	Fe	26	15.5	nd	30.2	3.1	13.0	nd
Potassium	K	19	1765.8	nd	4191.1	5256.8	5436.1	4456.1
Manganese	Mn	25	31.3	2.4	23.8	17.3	8.3	3.2
Molybdenum	Mo	42	nd	nd	nd	nd	nd	nd
Nickel	Ni	28	1.2	nd	1.2	nd	12.6	0.1
Lead	Pb	82	7.3	nd	45.7	54.7	17.6	6.0
Tin	Sn	50	nd	nd	nd	nd	nd	nd
Titanium	Ti	22	nd	nd	nd	nd	nd	nd
Vanadium	V	23	nd	nd	nd	nd	nd	nd
Zinc	Zn	30	1253.8	nd	4733.5	1310.2	202.8	nd
COMBUSTION GASES								
Carbon Monoxide (ppm)	CO		3000	23000	1000	3000	1000	3250
Carbon Dioxide (%)	CO2		12	15	3.5	11	7	7.5

NA: Not Available; nd: Non Detectable = 0

APPENDIX B-2

RATIO OF CHEMICAL SPECIES TO BEEP MEASURED IN WOODSMOKE EMISSIONS FOR EACH INDIVIDUAL TEST

Stove Type A

	Date Sampled		June 25	June 28	July 3	Aug. 30	Sept. 3	June 17	Sept. 4	Sept. 10
	Stove Type		A	A	A	A	A	A	A	A
	Wood Type		Pine	Pine	Pine	Birch	Birch	Maple	Maple	Maple
	Volume (Dscm)		0.664	0.857	0.415	0.706	0.917	1.025	0.735	0.872
	Symbol	Spec. #	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP
ORGANICS										
Fluorene	FLOR	222	6.33E-01	7.60E-01	2.96E+00	2.84E+00	3.77E+00	3.56E+00	4.87E-01	2.30E+00
Dibenzothiophene	DIBE	221	7.49E-03	0.00E+00	2.29E-02	0.00E+00	0.00E+00	4.73E-02	1.53E-02	0.00E+00
Phenanthrene	PHEN	231	2.93E-02	4.97E+00	7.44E+00	1.09E+00	1.11E+01	2.60E+01	4.72E-01	2.19E+00
Anthracene	ANTH	211	1.63E+00	0.00E+00	0.00E+00	2.46E+00	3.40E+00	4.08E+00	0.00E+00	6.80E-01
Acridine	ACRI	210	0.00E+00	1.05E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.90E-01	0.00E+00
Carbazole	CARB	218	1.43E-02	1.81E+00	4.15E-02	6.38E-02	3.45E-02	1.62E-01	1.64E-02	5.16E-02
Fluoranthene	FLUO	223	1.02E+00	1.58E+00	8.24E+00	7.81E+00	7.53E+00	1.56E+01	4.30E-01	3.09E+00
Pyrene	PYRE	232	2.90E+00	1.74E-01	6.36E+00	6.34E+00	7.48E+00	1.11E+01	9.71E-01	3.73E+00
Retene	RETE	233	6.78E-01	0.00E+00	3.29E-02	5.13E-01	1.73E-02	4.10E-02	2.03E-02	0.00E+00
Tetracosane	TETR	234	7.34E-02	4.31E+00	3.41E-01	0.00E+00	0.00E+00	1.98E-01	2.17E-03	0.00E+00
Pentacosane	TRIA	235	1.16E-01	4.63E+00	4.85E-01	0.00E+00	0.00E+00	6.61E-01	0.00E+00	0.00E+00
Chrysene	CHRY	219	1.62E+00	1.39E+00	2.18E+00	1.66E+00	1.80E+00	2.55E+00	8.01E-01	1.52E+00
1,2-Benzanthracene	BZA		2.08E+00	1.20E+00	2.87E+00	2.08E+00	2.32E+00	3.14E+00	1.18E+00	2.22E+00
Hexacosane	HEXA	225	9.91E-02	5.85E+01	3.90E-01	3.76E-01	0.00E+00	1.87E-01	0.00E+00	4.75E-02
Octacosane	OCTA	228	6.62E-02	2.01E+00	3.97E-01	1.89E-01	0.00E+00	4.12E-01	0.00E+00	5.01E-02
Benzo(b+k)Fluoranthene	BEBF	213	4.88E+00	6.44E+00	5.82E+00	3.82E+00	4.22E+00	6.86E+00	9.61E-01	3.32E+00
Nonacosane	NONA	227	6.58E-02	3.58E+00	3.68E-01	1.81E-01	0.00E+00	2.78E-01	0.00E+00	4.68E-02
Benzo(e)Pyrene	BEEP	215	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Benzo(a)Pyrene	BAP	212	1.47E+00	1.82E+00	1.38E+00	1.35E+00	1.50E+00	1.60E+00	9.70E-01	1.49E+00
Perylene	PERY	230	3.24E-01	0.00E+00	2.76E-01	4.25E-01	5.11E-01	3.23E-01	2.05E-01	3.46E-01
Indeno(1,2,3-c,d)Pyrene	INDE	226	7.09E-01	2.85E+00	1.39E+00	1.45E+00	1.68E+00	1.90E+00	1.25E+00	1.27E+00
Dibenzo(a,h)Anthracene	DIAA	220	1.19E-01	1.23E+00	2.12E-01	2.70E-01	2.45E-01	1.49E-01	2.73E-01	3.14E-01
Benzo(ghi)Perylene	BEGP	216	4.04E-01	5.47E-01	1.49E+00	2.02E+00	2.78E+00	1.42E+00	1.68E+00	1.63E+00
INORGANICS										
Silver	Ag	47	1.62E-03	2.17E-01		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Aluminum	Al	13	0.00E+00	0.00E+00		0.00E+00	1.57E-01		1.51E+00	3.59E+00
Bismuth	Bi	83	0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Boron	B	5	0.00E+00	0.00E+00		0.00E+00	0.00E+00		1.17E+00	1.88E+00
Barium	Ba	56	0.00E+00	0.00E+00		0.00E+00	0.00E+00		2.55E+00	5.33E+00
Beryllium	Be	4	0.00E+00	0.00E+00		0.00E+00	0.00E+00		8.94E-04	0.00E+00
Cadmium	Cd	48	1.97E-02	1.47E+00		3.37E-01	8.25E-01		2.16E-02	1.55E-01
Calcium	Ca	20	0.00E+00	0.00E+00		0.00E+00	0.00E+00		3.61E-01	3.65E-01
Cobalt	Co	27	0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Chromium	Cr	24	2.71E-03	2.89E-01		0.00E+00	3.13E-02		1.67E-03	1.23E-02
Copper	Cu	29	1.90E-02	7.79E-01		3.01E-02	3.26E-01		1.54E-03	1.24E-02
Iron	Fe	26	0.00E+00	0.00E+00		0.00E+00	9.63E-01		1.72E-02	1.19E-01
Potassium	K	19	4.33E+00	2.31E+01		2.90E+01	4.95E+01		3.98E+00	3.46E+01
Manganese	Mn	25	6.20E-02	8.46E+00		1.15E-01	4.95E-01		7.22E-03	6.64E-02
Molybdenum	Mo	42	0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Nickel	Ni	28	0.00E+00	0.00E+00		0.00E+00	1.08E-01		6.86E-03	1.10E-02
Lead	Pb	82	2.44E-02	1.52E+00		1.20E+00	3.77E+00		4.19E-02	4.83E-01
Tin	Sn	50	0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Titanium	Ti	22	0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Vanadium	V	23	0.00E+00	0.00E+00		0.00E+00	0.00E+00		0.00E+00	0.00E+00
Zinc	Zn	30	0.00E+00	0.00E+00		0.00E+00	1.25E+02		2.19E+00	1.33E+01

Stove Type B

	Date Sampled		Aug. 7	Aug. 12	July 30	Aug. 1	July 22	July 24
	Stove Type		B	B	B	B	B	B
	Wood Type		Pine	Pine	Birch	Birch	Maple	Maple
	Volume (Dscm)		1.02	0.9	1.124	0.977	0.771	0.861
	Symbol	Spec. #	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP
ORGANICS								
Fluorene	FLOR	222	2.91E+00	2.88E+00	3.89E+00	2.87E+00	2.58E+00	4.73E+00
Dibenzothiophene	DIBE	221	0.00E+00	0.00E+00	6.00E-02	0.00E+00	9.66E-03	4.62E-02
Phenanthrene	PHEN	231	1.78E+00	9.83E-01	7.05E+00	6.44E-01	3.25E+00	2.11E+00
Anthracene	ANTH	211	3.14E-01	0.00E+00	1.19E+00	0.00E+00	-3.15E-01	0.00E+00
Acridine	ACRI	210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Carbazole	CARB	218	1.11E-02	9.55E-03	7.23E-02	8.84E-03	4.39E-02	1.48E-01
Fluoranthene	FLUO	223	2.20E+00	2.26E+00	5.00E+00	1.60E+00	4.52E+00	1.45E+00
Pyrene	PYRE	232	2.33E+00	1.97E+00	6.45E+00	3.84E+00	2.43E+00	5.44E+00
Retene	RETE	233	7.37E+00	9.30E-01	2.02E-01	4.51E-01	0.00E+00	0.00E+00
Tetracosane	TETR	234	0.00E+00	0.00E+00	1.83E-02	2.76E-02	2.86E-02	4.53E-02
Pentacosane	TRIA	235	1.73E-02	3.48E-02	5.53E-01	1.36E-02	7.22E-02	6.71E-02
Chrysene	CHRY	219	1.60E+00	2.00E+00	1.81E+00	1.98E+00	1.10E+00	2.87E+00
1,2-Benzanthracene	BZA		2.08E+00	2.72E+00	2.43E+00	2.71E+00	1.50E+00	3.15E+00
Hexacosane	HEXA	225	0.00E+00	0.00E+00	8.72E-02	6.98E-03	4.53E-02	1.11E-01
Octacosane	OCTA	228	3.19E-02	3.99E-02	8.65E-02	2.56E-02	2.97E-02	3.10E-02
Benzo(b+k)Fluoranthene	BEBF	213	6.63E+00	6.53E+00	5.11E+00	2.58E+00	4.02E+00	6.47E+00
Nonacosane	NONA	227	1.08E-02	1.70E-02	7.46E-02	1.50E-02	3.89E-02	2.86E-02
Benzo(e)Pyrene	BEEP	215	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Benzo(a)Pyrene	BAP	212	1.86E+00	1.45E+00	1.93E+00	1.74E+00	1.40E+00	2.36E+00
Perylene	PERY	230	3.99E-01	3.36E-01	4.02E-01	3.78E-01	2.89E-01	4.31E-01
Indeno(1,2,3-c,d)Pyrene	INDE	226	1.03E+00	1.07E+00	9.05E-01	1.01E+00	7.32E-01	9.68E-01
Dibenzo(a,h)Anthracene	DIAA	220	4.52E-01	4.92E-01	2.97E-01	4.07E-01	2.80E-01	3.30E-01
Benzo(ghi)Perylene	BEGP	216	1.12E+00	1.23E+00	1.13E+00	1.16E+00	7.98E-01	1.16E+00
INORGANICS								
Silver	Ag	47	2.17E-02	7.23E-03	0.00E+00	0.00E+00	5.09E-03	0.00E+00
Aluminum	Al	13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bismuth	Bi	83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Boron	B	5	0.00E+00	9.05E+00	2.11E+00	1.62E+00	0.00E+00	2.71E+00
Barium	Ba	56	0.00E+00	8.39E+00	0.00E+00	0.00E+00	0.00E+00	4.69E-01
Beryllium	Be	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium	Cd	48	3.13E-02	5.14E-02	7.47E-02	1.62E-01	2.72E-02	5.65E-02
Calcium	Ca	20	0.00E+00	6.09E-01	0.00E+00	8.73E-02	0.00E+00	0.00E+00
Cobalt	Co	27	8.05E-02	6.87E-02	3.79E-02	6.60E-02	0.00E+00	2.56E-02
Chromium	Cr	24	2.06E-03	1.33E-02	3.51E-03	6.07E-03	1.70E-03	7.82E-03
Copper	Cu	29	1.55E-02	2.68E-02	8.63E-03	3.00E-02	1.78E-02	1.68E-02
Iron	Fe	26	7.43E-02	1.16E-01	7.37E-02	1.55E-01	0.00E+00	9.81E-02
Potassium	K	19	1.28E+00	2.79E+01	1.71E+00	4.51E+01	5.55E+01	3.54E+01
Manganese	Mn	25	3.13E-01	1.45E-01	1.18E-01	2.10E-01	1.82E-02	3.23E-02
Molybdenum	Mo	42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel	Ni	28	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead	Pb	82	5.57E-02	1.19E-01	1.73E-01	3.53E-01	5.34E-02	2.24E-01
Tin	Sn	50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Titanium	Ti	22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Vanadium	V	23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc	Zn	30	0.00E+00	9.89E+00	4.16E+00	1.21E+01	0.00E+00	2.78E+00

Stove Type C

	Date Sampled		Aug. 27	Aug. 29	Aug. 23	Aug. 26	Aug. 20	Sept. 11
	Stove Type		C	C	C	C	C	C
	Wood Type		Pine	Pine	Birch	Birch	Maple	Maple
	Volume (Dscm)		0.851	0.43	0.893	0.906	0.843	1.558
	Symbol	Spec. #	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP	Ratio to BEEP
ORGANICS								
Fluorene	FLOR	222	3.68E+00	1.68E+00	4.38E-01	1.24E+00	1.00E+00	4.68E+00
Dibenzothiophene	DIBE	221	0.00E+00	6.40E-02	0.00E+00	0.00E+00	1.59E-02	5.20E-02
Phenanthrene	PHEN	231	0.00E+00	1.52E+00	1.17E+00	1.95E+00	4.01E-01	2.99E+00
Anthracene	ANTH	211	3.90E+00	1.98E+00	0.00E+00	5.29E-01	1.06E+00	2.94E+00
Acridine	ACRI	210	0.00E+00	7.99E-01	0.00E+00	0.00E+00	0.00E+00	3.63E+00
Carbazole	CARB	218	3.73E-02	3.44E-01	2.79E-02	3.14E-02	0.00E+00	3.25E-01
Fluoranthene	FLUO	223	1.04E+01	2.19E+00	2.40E+00	1.93E+00	1.11E+00	3.70E+00
Pyrene	PYRE	232	6.66E+00	3.47E+00	2.26E+00	2.85E+00	1.19E+00	3.56E+00
Retene	RETE	233	4.96E+00	4.73E+00	1.93E-01	4.11E-02	3.94E-02	7.16E-01
Tetracosane	TETR	234	0.00E+00	2.74E-02	0.00E+00	0.00E+00	2.54E-02	0.00E+00
Pentacosane	TRIA	235	0.00E+00	0.00E+00	1.09E-01	0.00E+00	0.00E+00	0.00E+00
Chrysene	CHRY	219	3.99E+00	2.72E+00	1.28E+00	1.25E+00	1.28E+00	6.37E+00
1,2-Benzanthracene	BZA		5.25E+00	3.50E+00	2.08E+00	1.83E+00	1.83E-01	9.41E+00
Hexacosane	HEXA	225	0.00E+00	0.00E+00	9.94E-02	0.00E+00	2.49E-02	4.12E-01
Octacosane	OCTA	228	0.00E+00	0.00E+00	5.78E-02	0.00E+00	0.00E+00	0.00E+00
Benzo(b+k)Fluoranthene	BEBF	213	4.77E+00	1.77E+00	3.27E+00	2.83E+00	6.79E-01	9.20E+00
Nonacosane	NONA	227	3.49E-01	0.00E+00	1.42E-02	0.00E+00	0.00E+00	8.28E-03
Benzo(e)Pyrene	BEEP	215	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Benzo(a)Pyrene	BAP	212	3.28E-01	1.66E+00	2.14E+00	1.39E+00	2.65E-01	3.96E+00
Perylene	PERY	230	2.07E-01	2.58E-01	4.64E-01	3.19E-01	3.70E-01	5.84E-01
Indeno(1,2,3-c,d)Pyrene	INDE	226	1.58E+00	9.50E-01	1.45E+00	1.12E+00	8.85E-01	8.85E+00
Dibenzo(a,h)Anthracene	DIAA	220	2.69E-01	3.92E-01	3.30E-01	2.67E-01	2.03E-01	1.97E+00
Benzo(ghi)Perylene	BEGP	216	9.08E-01	8.29E-01	1.87E+00	1.47E+00	1.06E+00	1.28E+01
INORGANICS								
Silver	Ag	47	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminum	Al	13	8.86E+01	0.00E+00	2.62E+01	0.00E+00	0.00E+00	0.00E+00
Bismuth	Bi	83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Boron	B	5	1.29E+02	0.00E+00	3.05E+01	0.00E+00	1.66E-02	0.00E+00
Barium	Ba	56	1.60E+02	0.00E+00	4.93E+01	0.00E+00	0.00E+00	0.00E+00
Beryllium	Be	4	5.70E-02	0.00E+00	1.24E-02	0.00E+00	0.00E+00	0.00E+00
Cadmium	Cd	48	5.79E-01	4.80E-03	2.42E-01	7.40E-02	8.13E-03	4.89E-02
Calcium	Ca	20	4.40E+01	0.00E+00	0.00E+00	3.83E+00	0.00E+00	0.00E+00
Cobalt	Co	27	1.60E-01	4.07E-03	4.68E-02	1.98E-02	1.07E-02	0.00E+00
Chromium	Cr	24	6.08E-02	0.00E+00	1.01E-02	0.00E+00	5.12E-04	0.00E+00
Copper	Cu	29	1.39E-01	0.00E+00	4.81E-02	5.24E-02	2.73E-02	2.15E-02
Iron	Fe	26	1.51E+00	0.00E+00	3.71E-01	2.78E-02	4.22E-02	0.00E+00
Potassium	K	19	1.71E+02	0.00E+00	5.15E+01	4.72E+01	1.76E+01	9.59E+01
Manganese	Mn	25	3.04E+00	4.20E-03	2.92E-01	1.55E-01	2.70E-02	6.95E-02
Molybdenum	Mo	42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel	Ni	28	1.18E-01	0.00E+00	1.42E-02	0.00E+00	4.08E-02	3.22E-03
Lead	Pb	82	7.07E-01	0.00E+00	5.61E-01	4.92E-01	5.68E-02	1.30E-01
Tin	Sn	50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Titanium	Ti	22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Vanadium	V	23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc	Zn	30	1.22E+02	0.00E+00	5.81E+01	1.18E+01	6.56E-01	0.00E+00

APPENDIX B-3

AVERAGE CONCENTRATION OF CHEMICAL SPECIES PRODUCED BY THE COMBUSTION OF EACH WOOD TYPE IN EACH OF THE WOOD STOVE MODELS

Stove Type A

		Stove Type	A	A	A	A	A
		Wood Type	Pine	Birch	Maple	All Woods	All Woods
	Symbol	Spec. #	Average Conc (µg/m3)	Average Conc (µg/m3)	Average Conc (µg/m3)	Average Conc (µg/m3)	Std. Dev. Conc (µg/m3)
ORGANICS							
Fluorene	FLOR	222	103.9	67.1	200.6	131.0	128.3
Dibenzothiophene	DIBE	221	1.0	0.0	4.0	1.9	4.3
Phenanthrene	PHEN	231	166.9	115.4	260.5	189.1	185.5
Anthracene	ANTH	211	100.9	59.4	31.8	64.6	107.0
Acridine	ACRI	210	0.8	0.0	200.4	75.4	227.1
Carbazole	CARB	218	3.1	1.0	6.1	3.7	4.0
Fluoranthene	FLUO	223	243.2	158.3	245.0	222.6	169.9
Pyrene	PYRE	232	317.3	141.1	387.5	299.6	269.0
Retene	RETE	233	42.6	6.0	5.3	19.4	46.3
Tetracosane	TETR	234	15.0	0.0	1.1	6.1	8.8
Pentacosane	TRIA	235	21.0	0.0	2.0	8.6	12.8
Chrysene	CHRY	219	148.5	35.5	254.8	160.1	220.1
1,2-Benzanthracene	BZA		191.6	45.0	371.9	222.6	320.6
Hexacosane	HEXA	225	56.7	4.2	1.9	23.0	45.6
Octacosane	OCTA	228	14.2	2.1	2.7	6.8	9.2
Benzo(b+k)Fluoranthene	BEBF	213	432.4	82.4	360.3	317.8	358.7
Nonacosane	NONA	227	14.6	2.0	2.2	6.8	8.6
Benzo(e)Pyrene	BEEP	215	84.2	20.6	285.5	143.8	274.1
Benzo(a)Pyrene	BAP	212	122.2	29.2	293.9	163.3	265.7
Perylene	PERY	230	26.0	9.6	63.1	35.8	56.0
Indeno(1,2,3-c,d)Pyrene	INDE	226	76.1	32.1	359.1	171.2	340.0
Dibenzo(a,h)Anthracene	DIAA	220	12.9	5.3	78.9	35.7	75.1
Benzo(ghi)Perylene	BEGP	216	57.7	48.6	478.2	213.1	463.5
INORGANICS							
Silver	Ag	47	0.4	0.0	0.0	0.1	0.2
Aluminum	Al	13	0.0	1.5	729.6	243.7	503.4
Bismuth	Bi	83	0.0	0.0	0.0	0.0	0.0
Boron	B	5	0.0	0.0	526.7	175.6	390.1
Barium	Ba	56	0.0	0.0	1200.4	400.1	849.6
Beryllium	Be	4	0.0	0.0	0.3	0.1	0.3
Cadmium	Cd	48	3.4	11.5	14.9	9.9	6.5
Calcium	Ca	20	0.0	0.0	153.1	51.0	120.7
Cobalt	Co	27	0.0	0.0	0.0	0.0	0.0
Chromium	Cr	24	0.6	0.3	1.2	0.7	0.5
Copper	Cu	29	2.6	3.4	1.1	2.4	2.3
Iron	Fe	26	0.0	8.9	11.7	6.9	8.7
Potassium	K	19	426.0	787.1	3015.8	1409.7	1401.8
Manganese	Mn	25	14.9	5.9	5.6	8.8	6.1
Molybdenum	Mo	42	0.0	0.0	0.0	0.0	0.0
Nickel	Ni	28	0.0	1.0	3.1	1.4	2.2
Lead	Pb	82	3.9	48.6	36.9	29.8	27.4
Tin	Sn	50	0.0	0.0	0.0	0.0	0.0
Titanium	Ti	22	0.0	0.0	0.0	0.0	0.0
Vanadium	V	23	0.0	0.0	0.0	0.0	0.0
Zinc	Zn	30	0.0	1159.8	1412.1	857.3	1105.4

Stove Type B

	Stove Type		B	B	B	B	B
	Wood Type		Pine	Birch	Maple	All Woods	All Woods
	Symbol	Spec. #	Average Conc (µg/m3)	Average Conc (µg/m3)	Average Conc (µg/m3)	Average Conc (µg/m3)	Std. Dev. Conc (µg/m3)
ORGANICS							
Fluorene	FLOR	222	180.7	293.5	389.2	287.8	136.6
Dibenzothiophene	DIBE	221	0.0	2.5	3.0	1.8	2.7
Phenanthrene	PHEN	231	86.7	326.9	280.7	231.4	227.8
Anthracene	ANTH	211	10.0	50.3	16.0	25.4	42.9
Acridine	ACRI	210	0.0	0.0	0.0	0.0	0.0
Carbazole	CARB	218	0.6	3.5	10.3	4.8	6.6
Fluoranthene	FLUO	223	139.1	283.2	309.1	243.8	168.4
Pyrene	PYRE	232	134.4	445.2	420.0	333.2	218.4
Retene	RETE	233	262.2	28.8	0.0	97.0	200.2
Tetracosane	TETR	234	0.0	2.0	3.9	2.0	2.1
Pentacosane	TRIA	235	1.6	24.0	7.3	11.0	19.4
Chrysene	CHRY	219	112.2	165.7	212.4	163.4	85.6
1,2-Benzanthracene	BZA		149.2	224.6	248.1	207.3	85.0
Hexacosane	HEXA	225	0.0	4.0	8.3	4.1	5.4
Octacosane	OCTA	228	2.2	4.8	3.2	3.4	2.2
Benzo(b+k)Fluoranthene	BEBF	213	410.7	331.8	557.0	433.2	166.6
Nonacosane	NONA	227	0.9	3.8	3.5	2.7	2.4
Benzo(e)Pyrene	BEEP	215	62.4	87.2	105.4	85.0	21.4
Benzo(a)Pyrene	BAP	212	103.6	160.0	200.0	154.5	62.6
Perylene	PERY	230	23.0	34.0	38.2	31.7	9.9
Indeno(1,2,3-c,d)Pyrene	INDE	226	65.7	83.7	90.0	79.8	17.1
Dibenzo(a,h)Anthracene	DIAA	220	29.4	30.8	32.3	30.8	5.0
Benzo(ghi)Perylene	BEGP	216	73.4	99.9	104.1	92.5	22.9
INORGANICS							
Silver	Ag	47	0.9	0.0	0.3	0.4	0.6
Aluminum	Al	13	0.0	0.0	0.0	0.0	0.0
Bismuth	Bi	83	0.0	0.0	0.0	0.0	0.0
Boron	B	5	278.0	162.0	147.7	195.9	229.3
Barium	Ba	56	257.8	0.0	25.6	94.4	227.1
Beryllium	Be	4	0.0	0.0	0.0	0.0	0.0
Cadmium	Cd	48	2.6	10.4	4.5	5.8	5.1
Calcium	Ca	20	18.7	3.9	0.0	7.5	16.4
Cobalt	Co	27	4.7	4.6	1.4	3.5	2.3
Chromium	Cr	24	0.5	0.4	0.5	0.5	0.3
Copper	Cu	29	1.3	1.7	1.8	1.6	0.8
Iron	Fe	26	5.9	10.1	5.3	7.1	5.3
Potassium	K	19	897.6	2100.3	4758.8	2585.6	2508.4
Manganese	Mn	25	14.4	14.4	2.7	10.5	8.2
Molybdenum	Mo	42	0.0	0.0	0.0	0.0	0.0
Nickel	Ni	28	0.0	0.0	0.0	0.0	0.0
Lead	Pb	82	5.4	23.2	14.9	14.5	12.5
Tin	Sn	50	0.0	0.0	0.0	0.0	0.0
Titanium	Ti	22	0.0	0.0	0.0	0.0	0.0
Vanadium	V	23	0.0	0.0	0.0	0.0	0.0
Zinc	Zn	30	303.9	721.8	151.6	392.4	452.6

Stove Type C

	Stove Type		C	C	C	C	C
	Wood Type		Pine	Birch	Maple	All Woods	All Woods
	Symbol	Spec. #	Average Conc (µg/m3)	Average Conc (µg/m3)	Average Conc (µg/m3)	Average Conc (µg/m3)	Std. Dev. Conc (µg/m3)
ORGANICS							
Fluorene	FLOR	222	500.3	86.5	263.7	283.5	382.4
Dibenzothiophene	DIBE	221	18.3	0.0	3.7	7.3	15.9
Phenanthrene	PHEN	231	435.7	156.4	131.5	241.2	346.8
Anthracene	ANTH	211	586.0	29.4	232.4	282.6	473.2
Acridine	ACRI	210	228.2	0.0	84.4	104.2	203.0
Carbazole	CARB	218	98.4	2.9	7.6	36.3	86.1
Fluoranthene	FLUO	223	680.3	205.0	257.4	380.9	475.5
Pyrene	PYRE	232	1027.3	250.6	266.5	514.8	798.4
Retene	RETE	233	1377.4	10.1	22.7	470.1	1198.8
Tetracosane	TETR	234	7.8	0.0	3.9	3.9	7.2
Pentacosane	TRIA	235	0.0	4.5	0.0	1.5	4.0
Chrysene	CHRY	219	799.1	121.8	345.9	422.3	625.7
1,2-Benzanthracene	BZA		1028.2	186.5	246.9	487.2	827.4
Hexacosane	HEXA	225	0.0	4.0	13.4	5.8	8.3
Octacosane	OCTA	228	0.0	2.4	0.0	0.8	2.1
Benzo(b+k)Fluoranthene	BEBF	213	531.8	290.8	318.7	380.4	366.8
Nonacosane	NONA	227	1.8	0.6	0.2	0.9	1.6
Benzo(e)Pyrene	BEEP	215	290.9	96.3	177.8	188.4	235.3
Benzo(a)Pyrene	BAP	212	477.4	164.6	133.0	258.3	379.4
Perylene	PERY	230	74.9	36.6	70.8	60.8	62.3
Indeno(1,2,3-c,d)Pyrene	INDE	226	279.6	121.3	342.5	247.8	219.2
Dibenzo(a,h)Anthracene	DIAA	220	113.3	28.3	77.3	73.0	87.8
Benzo(ghi)Perylene	BEGP	216	241.5	158.0	462.6	287.4	241.3
INORGANICS							
Silver	Ag	47	0.0	0.0	0.0	0.0	0.0
Aluminum	Al	13	456.3	1066.4	0.0	507.6	959.5
Bismuth	Bi	83	0.0	0.0	0.0	0.0	0.0
Boron	B	5	666.5	1239.8	2.6	636.3	1148.5
Barium	Ba	56	824.9	2006.7	0.0	943.9	1798.9
Beryllium	Be	4	0.3	0.5	0.0	0.3	0.5
Cadmium	Cd	48	4.4	14.0	2.4	6.9	7.3
Calcium	Ca	20	226.6	212.8	0.0	146.5	248.8
Cobalt	Co	27	2.0	3.0	1.7	2.2	1.5
Chromium	Cr	24	0.3	0.4	0.1	0.3	0.4
Copper	Cu	29	0.7	4.9	4.7	3.4	3.6
Iron	Fe	26	7.8	16.7	6.5	10.3	12.9
Potassium	K	19	882.9	4724.0	4946.1	3517.7	2374.0
Manganese	Mn	25	16.8	20.5	5.8	14.4	12.8
Molybdenum	Mo	42	0.0	0.0	0.0	0.0	0.0
Nickel	Ni	28	0.6	0.6	6.4	2.5	5.5
Lead	Pb	82	3.6	50.2	11.8	21.9	25.0
Tin	Sn	50	0.0	0.0	0.0	0.0	0.0
Titanium	Ti	22	0.0	0.0	0.0	0.0	0.0
Vanadium	V	23	0.0	0.0	0.0	0.0	0.0
Zinc	Zn	30	626.9	3021.8	101.4	1250.1	1981.5

APPENDIX B-4

AVERAGE RATIO OF CHEMICAL SPECIES TO BEEP PRODUCED BY THE COMBUSTION OF EACH WOOD TYPE IN EACH OF THE WOOD STOVE MODELS

Stove Type A

		Stove Type	A	A	A	A	A
		Wood Type	Pine	Birch	Maple	All Woods	All Woods
	Symbol	Spec. #	Average Ratio to BEEP	Average Ratio to BEEP	Average Ratio to BEEP	Average Ratio to BEEP	Std. Dev. Ratio to BEEP
ORGANICS							
Fluorene	FLOR	222	1.45E+00	3.30E+00	2.11E+00	2.16E+00	1.44E+00
Dibenzothiophene	DIBE	221	1.01E-02	0.00E+00	2.08E-02	1.16E-02	1.79E-02
Phenanthrene	PHEN	231	4.15E+00	6.09E+00	9.55E+00	6.66E+00	9.30E+00
Anthracene	ANTH	211	5.44E-01	2.93E+00	1.59E+00	1.53E+00	1.74E+00
Acridine	ACRI	210	3.50E-01	0.00E+00	2.63E-01	2.30E-01	4.62E-01
Carbazole	CARB	218	6.21E-01	4.92E-02	7.66E-02	2.74E-01	6.64E-01
Fluoranthene	FLUO	223	3.61E+00	7.67E+00	6.38E+00	5.66E+00	5.51E+00
Pyrene	PYRE	232	3.14E+00	6.91E+00	5.28E+00	4.89E+00	3.90E+00
Retene	RETE	233	2.37E-01	2.65E-01	2.04E-02	1.63E-01	2.90E-01
Tetracosane	TETR	234	1.57E+00	0.00E+00	6.66E-02	6.15E-01	1.60E+00
Pentacosane	TRIA	235	1.74E+00	0.00E+00	2.20E-01	7.36E-01	1.70E+00
Chrysene	CHRY	219	1.73E+00	1.73E+00	1.62E+00	1.69E+00	5.57E-01
1,2-Benzanthracene	BZA		2.05E+00	2.20E+00	2.18E+00	2.14E+00	7.44E-01
Hexacosane	HEXA	225	1.97E+01	1.88E-01	7.82E-02	7.46E+00	2.21E+01
Octacosane	OCTA	228	8.23E-01	9.44E-02	1.54E-01	3.90E-01	7.20E-01
Benzo(b+k)Fluoranthene	BEBF	213	5.71E+00	4.02E+00	3.71E+00	4.54E+00	2.05E+00
Nonacosane	NONA	227	1.34E+00	9.04E-02	1.08E-01	5.65E-01	1.31E+00
Benzo(e)Pyrene	BEEP	215	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00
Benzo(a)Pyrene	BAP	212	1.56E+00	1.43E+00	1.35E+00	1.45E+00	2.58E-01
Perylene	PERY	230	2.00E-01	4.68E-01	2.91E-01	3.01E-01	1.63E-01
Indeno(1,2,3-c,d)Pyrene	INDE	226	1.65E+00	1.57E+00	1.47E+00	1.56E+00	6.68E-01
Dibenzo(a,h)Anthracene	DIAA	220	5.21E-01	2.57E-01	2.45E-01	3.52E-01	3.86E-01
Benzo(ghi)Perylene	BEGP	216	8.14E-01	2.40E+00	1.58E+00	1.50E+00	8.15E-01
INORGANICS							
Silver	Ag	47	1.09E-01	0.00E+00	0.00E+00	3.64E-02	9.67E-02
Aluminum	Al	13	0.00E+00	7.83E-02	2.55E+00	8.76E-01	1.60E+00
Bismuth	Bi	83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Boron	B	5	0.00E+00	0.00E+00	1.52E+00	5.08E-01	8.96E-01
Barium	Ba	56	0.00E+00	0.00E+00	3.94E+00	1.31E+00	2.43E+00
Beryllium	Be	4	0.00E+00	0.00E+00	4.47E-04	1.49E-04	4.00E-04
Cadmium	Cd	48	7.46E-01	5.81E-01	8.82E-02	4.72E-01	6.30E-01
Calcium	Ca	20	0.00E+00	0.00E+00	3.63E-01	1.21E-01	2.05E-01
Cobalt	Co	27	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Chromium	Cr	24	1.46E-01	1.57E-02	6.99E-03	5.61E-02	1.25E-01
Copper	Cu	29	3.99E-01	1.78E-01	6.97E-03	1.95E-01	3.42E-01
Iron	Fe	26	0.00E+00	4.81E-01	6.79E-02	1.83E-01	4.21E-01
Potassium	K	19	1.37E+01	3.92E+01	1.93E+01	2.41E+01	1.94E+01
Manganese	Mn	25	4.26E+00	3.05E-01	3.68E-02	1.53E+00	3.72E+00
Molybdenum	Mo	42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel	Ni	28	0.00E+00	5.38E-02	8.92E-03	2.09E-02	4.68E-02
Lead	Pb	82	7.70E-01	2.49E+00	2.62E-01	1.17E+00	1.54E+00
Tin	Sn	50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Titanium	Ti	22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Vanadium	V	23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc	Zn	30	0.00E+00	6.24E+01	7.74E+00	2.34E+01	5.47E+01

Stove Type B

		Stove Type	B	B	B	B	B
		Wood Type	Pine	Birch	Maple	All Woods	All Woods
	Symbol	Spec. #	Average Ratio to BEEP	Average Ratio to BEEP	Average Ratio to BEEP	Average Ratio to BEEP	Std. Dev. Ratio to BEEP
ORGANICS							
Fluorene	FLOR	222	2.90E+00	3.38E+00	3.66E+00	3.31E+00	9.05E-01
Dibenzothiophene	DIBE	221	0.00E+00	3.00E-02	2.79E-02	1.93E-02	2.94E-02
Phenanthrene	PHEN	231	1.38E+00	3.85E+00	2.68E+00	2.64E+00	2.57E+00
Anthracene	ANTH	211	1.57E-01	5.95E-01	1.57E-01	3.03E-01	5.05E-01
Acridine	ACRI	210	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Carbazole	CARB	218	1.03E-02	4.06E-02	9.57E-02	4.89E-02	5.98E-02
Fluoranthene	FLUO	223	2.23E+00	3.30E+00	2.98E+00	2.84E+00	1.67E+00
Pyrene	PYRE	232	2.15E+00	5.15E+00	3.93E+00	3.74E+00	2.02E+00
Retene	RETE	233	4.15E+00	3.27E-01	0.00E+00	1.49E+00	3.18E+00
Tetracosane	TETR	234	0.00E+00	2.30E-02	3.69E-02	2.00E-02	1.94E-02
Pentacosane	TRIA	235	2.61E-02	2.83E-01	6.97E-02	1.26E-01	2.30E-01
Chrysene	CHRY	219	1.80E+00	1.90E+00	1.99E+00	1.89E+00	6.35E-01
1,2-Benzanthracene	BZA		2.40E+00	2.57E+00	2.33E+00	2.43E+00	6.32E-01
Hexacosane	HEXA	225	0.00E+00	4.71E-02	7.79E-02	4.17E-02	5.26E-02
Octacosane	OCTA	228	3.59E-02	5.61E-02	3.03E-02	4.08E-02	2.51E-02
Benzo(b+k)Fluoranthene	BEBF	213	6.58E+00	3.84E+00	5.24E+00	5.22E+00	1.81E+00
Nonacosane	NONA	227	1.39E-02	4.48E-02	3.38E-02	3.08E-02	2.61E-02
Benzo(e)Pyrene	BEEP	215	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00
Benzo(a)Pyrene	BAP	212	1.66E+00	1.84E+00	1.88E+00	1.79E+00	3.84E-01
Perylene	PERY	230	3.67E-01	3.90E-01	3.60E-01	3.72E-01	5.63E-02
Indeno(1,2,3-c,d)Pyrene	INDE	226	1.05E+00	9.58E-01	8.50E-01	9.53E-01	1.34E-01
Dibenzo(a,h)Anthracene	DIAA	220	4.72E-01	3.52E-01	3.05E-01	3.76E-01	9.52E-02
Benzo(ghi)Perylene	BEGP	216	1.18E+00	1.14E+00	9.81E-01	1.10E+00	1.68E-01
INORGANICS							
Silver	Ag	47	1.44E-02	0.00E+00	2.54E-03	5.66E-03	9.23E-03
Aluminum	Al	13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Bismuth	Bi	83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Boron	B	5	4.52E+00	1.86E+00	1.36E+00	2.58E+00	3.68E+00
Barium	Ba	56	4.20E+00	0.00E+00	2.35E-01	1.48E+00	3.72E+00
Beryllium	Be	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Cadmium	Cd	48	4.13E-02	1.18E-01	4.19E-02	6.72E-02	5.44E-02
Calcium	Ca	20	3.04E-01	4.36E-02	0.00E+00	1.16E-01	2.67E-01
Cobalt	Co	27	7.46E-02	5.20E-02	1.28E-02	4.64E-02	3.36E-02
Chromium	Cr	24	7.66E-03	4.79E-03	4.76E-03	5.74E-03	4.80E-03
Copper	Cu	29	2.11E-02	1.93E-02	1.73E-02	1.93E-02	8.60E-03
Iron	Fe	26	9.50E-02	1.14E-01	4.90E-02	8.61E-02	5.68E-02
Potassium	K	19	1.46E+01	2.34E+01	4.55E+01	2.78E+01	2.45E+01
Manganese	Mn	25	2.29E-01	1.64E-01	2.53E-02	1.39E-01	1.22E-01
Molybdenum	Mo	42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel	Ni	28	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Lead	Pb	82	8.75E-02	2.63E-01	1.39E-01	1.63E-01	1.25E-01
Tin	Sn	50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Titanium	Ti	22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Vanadium	V	23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc	Zn	30	4.95E+00	8.15E+00	1.39E+00	4.83E+00	5.59E+00

Stove Type C

		Stove Type	C	C	C	C	C
		Wood Type	Pine	Birch	Maple	All Woods	All Woods
	Symbol	Spec. #	Average Ratio to BEEP	Average Ratio to BEEP	Average Ratio to BEEP	Average Ratio to BEEP	Std. Dev. Ratio to BEEP
ORGANICS							
Fluorene	FLOR	222	2.68E+00	8.36E-01	2.84E+00	2.12E+00	1.84E+00
Dibenzothiophene	DIBE	221	3.20E-02	0.00E+00	3.39E-02	2.20E-02	3.16E-02
Phenanthrene	PHEN	231	7.62E-01	1.56E+00	1.70E+00	1.34E+00	1.18E+00
Anthracene	ANTH	211	2.94E+00	2.64E-01	2.00E+00	1.74E+00	1.64E+00
Acridine	ACRI	210	3.99E-01	0.00E+00	1.82E+00	7.39E-01	1.59E+00
Carbazole	CARB	218	1.90E-01	2.97E-02	1.63E-01	1.28E-01	1.76E-01
Fluoranthene	FLUO	223	6.32E+00	2.16E+00	2.40E+00	3.63E+00	3.77E+00
Pyrene	PYRE	232	5.07E+00	2.55E+00	2.37E+00	3.33E+00	2.03E+00
Retene	RETE	233	4.84E+00	1.17E-01	3.77E-01	1.78E+00	2.62E+00
Tetracosane	TETR	234	1.37E-02	0.00E+00	1.27E-02	8.80E-03	1.50E-02
Pentacosane	TRIA	235	0.00E+00	5.47E-02	0.00E+00	1.82E-02	4.89E-02
Chrysene	CHRY	219	3.36E+00	1.27E+00	3.82E+00	2.82E+00	2.25E+00
1,2-Benzanthracene	BZA		4.38E+00	1.96E+00	4.80E+00	3.71E+00	3.58E+00
Hexacosane	HEXA	225	0.00E+00	4.97E-02	2.19E-01	8.94E-02	1.78E-01
Octacosane	OCTA	228	0.00E+00	2.89E-02	0.00E+00	9.64E-03	2.59E-02
Benzo(b+k)Fluoranthene	BEBF	213	3.27E+00	3.05E+00	4.94E+00	3.75E+00	3.29E+00
Nonacosane	NONA	227	1.75E-01	7.11E-03	4.14E-03	6.19E-02	1.54E-01
Benzo(e)Pyrene	BEEP	215	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00
Benzo(a)Pyrene	BAP	212	9.96E-01	1.77E+00	2.11E+00	1.63E+00	1.50E+00
Perylene	PERY	230	2.33E-01	3.92E-01	4.77E-01	3.67E-01	1.52E-01
Indeno(1,2,3-c,d)Pyrene	INDE	226	1.26E+00	1.28E+00	4.87E+00	2.47E+00	3.44E+00
Dibenzo(a,h)Anthracene	DIAA	220	3.30E-01	2.98E-01	1.09E+00	5.72E-01	7.55E-01
Benzo(ghi)Perylene	BEGP	216	8.68E-01	1.67E+00	6.94E+00	3.16E+00	5.20E+00
INORGANICS							
Silver	Ag	47	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Aluminum	Al	13	4.43E+01	1.31E+01	0.00E+00	1.91E+01	3.90E+01
Bismuth	Bi	83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Boron	B	5	6.47E+01	1.52E+01	8.31E-03	2.66E+01	5.67E+01
Barium	Ba	56	8.01E+01	2.47E+01	0.00E+00	3.49E+01	7.06E+01
Beryllium	Be	4	2.85E-02	6.19E-03	0.00E+00	1.16E-02	2.50E-02
Cadmium	Cd	48	2.92E-01	1.58E-01	2.85E-02	1.60E-01	2.45E-01
Calcium	Ca	20	2.20E+01	1.91E+00	0.00E+00	7.97E+00	1.94E+01
Cobalt	Co	27	8.19E-02	3.33E-02	5.37E-03	4.02E-02	6.67E-02
Chromium	Cr	24	3.04E-02	5.04E-03	2.56E-04	1.19E-02	2.66E-02
Copper	Cu	29	6.96E-02	5.03E-02	2.44E-02	4.81E-02	5.31E-02
Iron	Fe	26	7.53E-01	2.00E-01	2.11E-02	3.25E-01	6.53E-01
Potassium	K	19	8.57E+01	4.94E+01	5.67E+01	6.39E+01	6.80E+01
Manganese	Mn	25	1.52E+00	2.24E-01	4.82E-02	5.98E-01	1.31E+00
Molybdenum	Mo	42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Nickel	Ni	28	5.89E-02	7.11E-03	2.20E-02	2.94E-02	5.04E-02
Lead	Pb	82	3.54E-01	5.27E-01	9.33E-02	3.25E-01	3.27E-01
Tin	Sn	50	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Titanium	Ti	22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Vanadium	V	23	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Zinc	Zn	30	6.09E+01	3.50E+01	3.28E-01	3.20E+01	5.40E+01

APPENDIX C

FLUE GAS AND SAMPLING TRAIN PARAMETERS

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : JUNE 25 1991
RUN : 1
LOC. : STACK

TRAVERSE NO. 1

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
1	0.0	211	0.006	0.40	587.61	82	241	251	44	66	12.0
1	5.0	218	0.006	0.40	589.22	85	220	253	42	66	12.0
1	10.0	223	0.008	0.40	590.86	88	236	253	42	66	12.0
1	15.0	224	0.007	0.40	592.48	92	240	253	42	66	12.0
1	20.0	219	0.007	0.40	594.07	95	243	254	42	66	12.0
1	25.0	221	0.006	0.40	595.63	98	244	255	42	66	12.0
1	30.0	225	0.006	0.40	597.18	100	248	257	45	63	12.0
1	35.0	228	0.006	0.40	598.71	102	249	258	45	63	12.0
1	40.0	222	0.006	0.40	600.24	103	249	257	45	63	12.0
1	45.0	217	0.006	0.30	601.73	104	250	258	43	66	12.0
1	50.0	214	0.006	0.40	603.27	106	251	259	43	66	12.0
1	55.0	217	0.006	0.40	604.82	107	251	259	43	66	12.0
1	60.0	212	0.005	0.40	606.36	107	249	260	41	66	12.0
1	65.0	211	0.006	0.40	607.93	108	251	260	42	66	12.0
1	70.0	206	0.005	0.40	609.51	108	250	260	44	66	12.0
1	75.0	211	0.006	0.40	611.11	109	248	260	43	66	12.0
	80.0				612.71						
		217	0.006	0.39		99	245	257	43	65	12.0

STOVE TYPE: A

WOOD TYPE: Pine

TEST START:	13:40
TEST END:	14:57
TEDLAR BAG FILLED AT:	14:20 (Time = 40 minutes)
SAMPLE VOLUME:	0.664 DSm^3
FLUE GAS MOISTURE CONTENT:	12%
LOG ADDED AT:	No logs added during test

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : JUNE 28 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	237	0.003	0.70	614.06	90	238	256	32	71	12.0
1	5.0	232	0.004	0.70	616.29	93	260	258	32	71	12.0
1	10.0	226	0.003	0.70	618.47	97	265	260	32	71	12.0
1	15.0	229	0.003	0.70	620.66	100	265	259	33	71	12.0
1	20.0	232	0.003	0.70	622.82	103	262	258	33	72	12.0
1	25.0	228	0.003	0.70	624.99	106	260	258	35	72	12.0
1	30.0	226	0.002	0.70	627.16	108	259	259	35	72	12.0
1	35.0	224	0.003	0.70	629.32	110	257	258	37	73	12.0
1	40.0	320	0.005	0.60	631.42	112	264	260	41	73	12.0
1	45.0	330	0.003	0.60	633.45	113	269	260	41	74	12.0
1	50.0	260	0.004	0.60	635.49	114	267	261	44	75	12.0
1	55.0	250	0.004	0.60	637.55	114	264	260	44	76	12.0
1	60.0	237	0.004	0.60	639.55	115	264	260	46	77	12.0
1	65.0	226	0.004	0.60	641.58	115	264	259	44	77	12.0
1	70.0	218	0.004	0.60	643.64	116	263	256	43	76	12.0
1	75.0	228	0.003	0.60	645.69	116	261	258	41	76	12.0
	80.0				646.94						
		244	0.003	0.65		108	261	259	38	74	12.0

STOVE TYPE: A

WOOD TYPE: PINE

TEST START:	15:01
TEST END:	16:19
TEDLAR BAG FILLED AT:	15:58 (Time = 55 minutes)
SAMPLE VOLUME:	0.857 DSm^3
FLUE GAS MOISTURE CONTENT:	11%
LOG ADDED AT:	15:39 (Time = 35 minutes)

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : JULY 2 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	192	0.002	1.00	652.31	80	245	207	40	77	14.0
1	5.0	195	0.002	0.90	654.74	84	267	193	40	62	14.0
1	10.0	204	0.002	0.80	657.00	87	248	204	35	62	14.0
1	15.0	178	0.002	0.75	659.23	90	237	211	36	62	14.0
1	20.0	221	0.003	0.50	661.31	93	239	207	43	67	14.5
1	25.0	235	0.003	0.40	663.08	95	238	201	37	67	15.0
1	30.0	234	0.003	0.35	664.66	97	226	215	30	57	15.0
1	35.0	213	0.003	0.30	666.14	99	221	229	28	57	16.0
1	40.0	201	0.003	0.30	667.51	100	222	236	30	57	16.0
	45.0				667.93						
		208	0.003	0.59		91	238	211	35	63	14.7

STOVE TYPE: A

WOOD TYPE: PINE

TEST START:	16:29
TEST END:	17:10
TEDLAR BAG FILLED AT:	17:07 (Time = 40 minutes)
SAMPLE VOLUME:	0.415 DSm^3
FLUE GAS MOISTURE CONTENT:	20%
LOG ADDED AT:	16:49 (Time = 20 minutes)

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : AUGUST 30 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	212	0.007	0.50	126.31	89	244	259	40	76	13.0
1	5.0	276	0.007	0.50	128.20	90	242	264	41	76	13.0
1	10.0	283	0.008	0.50	130.04	93	243	266	44	76	13.0
1	15.0	272	0.007	0.50	131.83	97	258	267	44	75	13.0
1	20.0	285	0.007	0.50	133.63	101	262	266	47	75	13.0
1	25.0	293	0.007	0.50	135.41	103	258	266	44	74	13.0
1	30.0	269	0.006	0.50	137.19	106	271	267	41	74	13.0
1	35.0	260	0.006	0.50	139.01	107	261	268	38	73	13.0
1	40.0	230	0.006	0.60	140.88	109	264	267	38	70	12.8
1	45.0	238	0.006	0.50	142.71	110	247	264	41	70	13.0
1	50.0	229	0.005	0.50	144.56	111	256	266	41	69	13.0
1	55.0	251	0.008	0.50	146.34	112	254	267	45	69	13.0
1	60.0	271	0.007	0.50	148.06	114	257	267	47	69	13.0
1	65.0	257	0.007	0.50	149.82	114	269	267	48	70	13.0
1	70.0	245	0.007	0.50	151.62	116	267	267	49	71	13.0
	75.0				153.37						
		258	0.007	0.51		105	257	266	43	72	13.0

STOVE TYPE: A

WOOD TYPE: BIRCH

TEST START: 10:37

TEST END: 11:52

TEDLAR BAG FILLED AT: 11:35 (Time = 60 minutes)

SAMPLE VOLUME: 0.706 DSm^3

FLUE GAS MOISTURE CONTENT: 20%

LOG ADDED AT: 11:19 (Time = 45 and 50)

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : SEPTEMBER 3 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	177	0.007	0.80	154.77	82	271	260	46	60	13.0
1	5.0	194	0.004	0.80	157.17	85	240	260	50	60	13.0
1	10.0	201	0.008	0.80	159.44	89	237	265	48	60	13.0
1	15.0	206	0.009	0.80	161.70	93	254	267	46	60	13.0
1	20.0	209	0.008	0.80	163.95	96	259	268	46	61	13.0
1	25.0	203	0.007	0.80	166.21	99	258	269	45	61	13.0
1	30.0	199	0.007	0.80	168.49	101	262	253	46	62	13.0
1	35.0	210	0.007	0.80	170.79	104	257	261	48	62	13.0
1	40.0	204	0.007	0.80	173.07	105	255	257	47	62	13.0
1	45.0	197	0.008	0.80	175.39	107	252	257	46	63	13.0
1	50.0	195	0.007	0.80	177.66	107	253	257	47	63	13.0
1	55.0	186	0.006	0.80	179.99	108	244	255	47	63	13.0
1	60.0	192	0.005	0.80	182.37	109	248	252	48	64	13.0
1	65.0	176	0.005	0.90	184.76	110	233	255	48	65	12.8
1	70.0	184	0.004	0.80	187.16	111	238	251	51	65	13.0
	75.0				189.54						
		196	0.007	0.81		100	251	259	47	62	13.0

STOVE TYPE: A

WOOD TYPE: BIRCH

TEST START:	13:12
TEST END:	14:27
TEDLAR BAG FILLED AT:	Not Specified
SAMPLE VOLUME:	0.917 DSm^3
FLUE GAS MOISTURE CONTENT:	19%
LOG ADDED AT:	No logs added during test

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : JUNE 17 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	207	0.003	1.60	520.71	88	266	172	64	41	20.0
1	5.0	300	0.003	1.40	523.00	97	264	196	46	41	20.0
1	10.0	288	0.003	1.40	526.17	95	253	213	46	41	20.0
1	15.0	230	0.003	1.20	528.99	98	254	224	48	41	17.0
1	20.0	334	0.003	1.10	531.81	99	259	233	48	41	17.0
1	25.0	328	0.003	1.10	534.28	101	259	239	49	41	18.0
1	30.0	326	0.003	1.10	536.58	102	260	242	50	41	18.0
1	35.0	317	0.003	1.10	539.36	103	258	243	50	41	18.0
1	40.0	309	0.003	1.10	541.65	104	262	248	52	41	18.0
1	45.0	300	0.003	1.10	544.41	105	261	248	53	41	18.0
1	50.0	308	0.003	1.10	547.23	105	261	251	52	41	18.0
1	55.0	302	0.003	1.10	548.88	105	262	251	52	41	18.0
1	60.0	300	0.003	1.10	552.64	106	200	251	53	41	18.0
1	65.0	271	0.003	1.10	553.91	106	253	247	59	41	18.0
	70.0				558.23						
		294	0.003	1.19		101	255	233	52	41	18.3

STOVE TYPE: A

WOOD TYPE: MAPLE

TEST START: 15:23

TEST END: 16:34

TEDLAR BAG FILLED AT: 15:54 (Time = 30 minutes)

SAMPLE VOLUME: 1.025 DSm^3

FLUE GAS MOISTURE CONTENT: 9%

LOG ADDED AT: No logs added during test

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : SEPTEMBER 4 1991
RUN : 1
LOC. : STACK

TRAVERSE NO. 1

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
1	0.0	268	0.006	0.60	191.37	77	224	257	46	73	13.0
1	5.0	245	0.004	0.60	193.57	81	234	258	51	73	13.0
1	10.0	255	0.004	0.60	195.62	85	245	259	51	74	13.0
1	15.0	242	0.004	0.60	197.62	89	250	259	51	62	13.0
1	20.0	260	0.004	0.60	199.58	92	259	260	51	62	13.0
1	25.0	253	0.004	0.50	201.46	94	263	262	52	62	13.0
1	30.0	248	0.004	0.50	203.32	96	274	260	53	62	13.0
1	35.0	251	0.003	0.50	205.11	98	251	262	55	63	13.0
1	40.0	238	0.003	0.50	206.84	99	257	259	56	63	13.0
1	45.0	264	0.004	0.40	208.58	100	244	259	51	63	13.0
1	50.0	281	0.004	0.40	210.30	101	256	259	47	63	13.0
1	55.0	255	0.004	0.40	211.99	102	241	259	46	61	13.0
1	60.0	242	0.004	0.40	213.73	103	251	259	42	61	13.0
1	65.0	242	0.005	0.50	215.52	104	241	257	41	61	13.0
1	70.0	239	0.005	0.50	217.30	105	248	278	41	61	13.0
	75.0				219.08						
		252	0.004	0.51		95	249	260	49	64	13.0

STOVE TYPE: A

WOOD TYPE: MAPLE

TEST START:	15:40
TEST END:	16:55
TEDLAR BAG FILLED AT:	16:15 (Time = 35 minutes)
SAMPLE VOLUME:	0.735 DSm^3
FLUE GAS MOISTURE CONTENT:	19%
LOG ADDED AT:	No logs added during test
DAMPERS ADJUSTED:	Time = 5 minutes dampers were 3/4 closed Time = 40 minutes dampers opened slightly Time = 55 minutes dampers opened slightly Time = 60 minutes dampers fully opened

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : SEPTEMBER 10 1991
RUN : 1
LOC. : STACK

TRAVERSE NO. 1

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
1	0.0	174	0.005	0.80	225.90	78	242	245	40	51	13.0
1	5.0	193	0.005	0.70	228.26	81	242	247	43	51	13.0
1	10.0	227	0.006	0.70	230.49	85	268	250	41	51	13.0
1	15.0	254	0.008	0.70	232.72	89	275	253	41	53	13.0
1	20.0	256	0.008	0.70	234.93	92	271	256	40	54	13.0
1	25.0	267	0.007	0.70	237.12	95	262	258	38	55	13.0
1	30.0	254	0.007	0.70	239.31	97	248	259	38	55	13.0
1	35.0	258	0.008	0.70	241.49	100	251	259	37	55	13.0
1	40.0	248	0.007	0.70	243.68	101	257	260	38	56	13.0
1	45.0	252	0.007	0.70	245.85	103	264	261	39	56	13.0
1	50.0	239	0.007	0.70	247.98	103	264	261	42	57	13.0
1	55.0	228	0.007	0.70	250.19	105	260	261	45	57	13.0
1	60.0	228	0.007	0.70	252.40	106	256	261	47	58	13.0
1	65.0	208	0.006	0.70	254.60	106	255	260	49	58	13.0
1	70.0	275	0.007	0.70	256.74	106	256	260	54	59	13.0
	75.0				258.85						
		237	0.007	0.71		96	258	257	42	55	13.0

STOVE TYPE: A

WOOD TYPE: MAPLE

TEST START: 09:50

TEST END: 11:05

TEDLAR BAG FILLED AT: 10:30 (Time = 40 minutes)

SAMPLE VOLUME: 0.872 DSm^3

FLUE GAS MOISTURE CONTENT: 17%

LOG ADDED AT:
Time = 65 minutes small log added
Time = 60 minutes logs adjusted

DAMPERS ADJUSTED:
Time = 5 minutes damper opened slightly
Time = 30 minutes damper opened slightly

Note Standard Conditions:
Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : AUGUST 7 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	279	0.005	1.00	826.85	80	218	247	34	59	13.0
1	5.0	297	0.005	1.00	829.53	83	253	250	33	59	12.8
1	10.0	278	0.004	1.00	832.19	86	265	252	33	59	12.8
1	15.0	280	0.004	1.00	834.85	91	271	252	33	59	12.8
1	20.0	285	0.004	1.00	837.54	94	272	257	33	59	12.8
1	25.0	383	0.007	1.00	840.15	96	279	256	33	59	12.8
1	30.0	362	0.006	1.00	842.70	99	284	258	36	59	12.8
1	35.0	330	0.006	1.00	845.27	101	285	259	36	61	12.8
1	40.0	372	0.007	1.00	847.82	102	288	260	36	61	12.8
1	45.0	339	0.006	1.00	850.33	103	288	261	38	61	12.8
1	50.0	306	0.005	1.00	852.87	104	288	262	37	61	12.8
1	55.0	348	0.007	1.00	855.43	105	288	261	36	63	12.8
1	60.0	354	0.006	1.00	857.94	106	290	262	36	63	12.8
1	65.0	357	0.005	1.00	860.46	107	289	263	37	63	12.8
1	70.0	302	0.005	1.00	862.99	107	289	263	37	63	12.8
	75.0				865.53						
		325	0.005	1.00		97	276	258	35	61	12.8

STOVE TYPE: B

WOOD TYPE: PINE

TEST START:	13:40
TEST END:	15:25
TEDLAR BAG FILLED AT:	14:50 (Time = 40 minutes)
SAMPLE VOLUME:	0.020 DSm^3
FLUE GAS MOISTURE CONTENT:	7%
LOG ADDED AT:	Time = 20 minutes

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : AUGUST 12 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	210	0.017	0.90	866.22	80	230	244	35	54	13.0
1	5.0	218	0.017	0.90	868.66	84	262	245	34	54	13.0
1	10.0	217	0.016	0.90	871.08	88	277	248	33	54	12.8
1	15.0	217	0.015	0.80	873.50	92	284	250	32	54	12.8
1	20.0	221	0.013	0.80	875.88	96	287	253	32	55	12.8
1	25.0	209	0.016	0.80	878.23	98	289	242	34	55	12.8
1	30.0	217	0.012	0.80	880.57	100	284	252	31	56	12.8
1	35.0	220	0.015	0.80	882.88	103	284	251	31	57	12.8
1	40.0	216	0.013	0.80	885.16	105	285	254	33	57	12.8
1	45.0	201	0.012	0.80	887.36	106	282	253	32	58	12.8
1	50.0	233	0.012	0.70	889.57	106	282	253	33	59	13.0
1	55.0	208	0.012	0.70	891.79	107	282	254	33	60	13.0
1	60.0	218	0.011	0.70	894.00	108	281	254	34	60	13.0
1	65.0	203	0.012	0.70	896.21	109	281	253	34	60	13.0
1	70.0	194	0.012	0.70	898.44	110	280	255	35	60	13.0
	75.0				900.66						
		213	0.014	0.79		99	278	251	33	57	12.9

STOVE TYPE: B

WOOD TYPE: PINE

TEST START:	14:40
TEST END:	15:55
TEDLAR BAG FILLED AT:	15:20 (Time = 40 minutes)
SAMPLE VOLUME:	0.900 DSm^3
FLUE GAS MOISTURE CONTENT:	13%
LOG ADDED AT:	Time = 45 minutes

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : JULY 24 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	319	0.017	0.70	701.05	83	194	268	36	69	13.0
1	5.0	280	0.012	0.70	703.27	86	233	277	40	69	13.0
1	10.0	262	0.010	0.70	705.50	89	252	248	47	69	12.8
1	15.0	272	0.012	0.70	707.75	93	253	253	46	69	12.8
1	20.0	283	0.013	0.70	709.99	96	251	270	42	69	12.8
1	25.0	275	0.014	0.70	712.20	99	249	283	42	69	12.8
1	30.0	284	0.011	0.70	714.36	100	253	293	42	69	12.8
1	35.0	246	0.011	0.70	716.54	103	260	281	49	69	12.8
1	40.0	253	0.011	0.70	718.70	104	264	262	51	69	12.8
1	45.0	245	0.012	0.70	720.84	106	267	265	46	69	12.8
1	50.0	252	0.011	0.70	723.04	107	263	262	44	72	12.8
1	55.0	258	0.012	0.70	725.22	107	259	263	45	72	12.8
1	60.0	248	0.012	0.70	727.39	108	258	261	45	72	12.8
1	65.0	243	0.011	0.70	729.57	108	259	261	47	72	12.8
1	70.0	239	0.009	0.70	731.74	108	257	260	46	73	12.8
	75.0				733.92						
		264	0.012	0.70		100	251	267	45	70	12.8

STOVE TYPE: B

WOOD TYPE: MAPLE

TEST START:	15:25
TEST END:	16:41
TEDLAR BAG FILLED AT:	16:02 (Time = 40 minutes)
SAMPLE VOLUME:	0.816 DSm^3
FLUE GAS MOISTURE CONTENT:	15%
LOG ADDED AT:	Time = 25 minutes

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT	: ENVIRONMENT ONTARIO	DATE	: JULY 30 1991
JOBSITE	: WATERLOO ONTARIO	RUN	: 1
REF.No.	: J2254	LOC.	: STACK

TRAVERSE NO. 1

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
1	0.0	208	0.012	1.10	736.20	78	166	250	29	60	13.0
1	5.0	216	0.013	1.10	739.03	83	168	254	36	60	13.0
1	10.0	209	0.011	1.10	741.82	86	221	258	36	60	13.0
1	15.0	212	0.009	1.10	744.66	89	253	258	34	60	13.0
1	20.0	210	0.009	1.10	747.49	92	258	259	35	60	13.0
1	25.0	204	0.010	1.10	750.34	95	258	260	34	60	13.0
1	30.0	203	0.008	1.10	753.18	97	260	261	33	60	13.0
1	35.0	318	0.012	1.10	756.03	99	263	262	36	60	12.8
1	40.0	264	0.010	1.10	758.59	101	264	262	34	60	12.8
1	45.0	222	0.010	1.10	761.58	101	259	265	35	60	12.8
1	50.0	198	0.011	1.10	764.45	102	260	263	34	60	12.8
1	55.0	210	0.008	1.10	767.30	103	261	262	35	65	12.8
1	60.0	186	0.007	1.10	770.15	103	256	261	36	65	12.8
1	65.0	183	0.007	1.10	773.01	103	258	260	36	65	12.8
1	70.0	171	0.006	1.10	775.87	103	255	263	36	65	12.8
	75.0				778.74						
		214	0.009	1.10		96	244	260	35	61	12.9

STOVE TYPE: B

WOOD TYPE: BIRCH

TEST START:	15:31
TEST END:	17:08
TEDLAR BAG FILLED AT:	16:30 (Time = 40 minutes)
SAMPLE VOLUME:	1.124 DSm^3
FLUE GAS MOISTURE CONTENT:	9%
LOG ADDED AT:	Time = 35 minutes Time = 50 minutes

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : AUGUST 1 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	254	0.005	0.90	781.95	83	182	243	38	65	13.0
1	5.0	233	0.005	0.90	784.46	87	218	246	37	65	13.0
1	10.0	213	0.004	0.90	786.97	90	239	249	35	65	12.9
1	15.0	206	0.004	0.90	789.47	94	244	253	35	65	12.9
1	20.0	195	0.003	0.90	791.97	97	248	253	33	65	12.9
1	25.0	197	0.003	0.90	794.46	100	249	254	34	65	12.9
1	30.0	193	0.003	0.90	796.95	102	250	256	35	65	12.9
1	35.0	202	0.003	0.90	799.15	104	251	257	37	67	12.9
1	40.0	219	0.003	0.90	801.94	105	252	257	37	67	12.9
1	45.0	225	0.004	0.90	804.34	106	255	257	39	69	12.9
1	50.0	212	0.004	0.90	806.73	108	254	259	36	69	12.9
1	55.0	203	0.004	0.90	809.15	109	255	258	35	69	12.9
1	60.0	198	0.004	0.90	811.58	110	255	259	34	69	12.9
1	65.0	210	0.004	0.90	814.04	110	254	259	34	68	12.9
1	70.0	200	0.004	0.90	816.58	110	255	259	33	68	12.9
	75.0				818.92						
		211	0.004	0.90		101	244	255	35	67	12.9

STOVE TYPE: B

WOOD TYPE: BIRCH

TEST START: 13:20

TEST END: 14:46

TEDLAR BAG FILLED AT: 14:05 (Time = 45 minutes)

SAMPLE VOLUME: 0.977 DSm^3

FLUE GAS MOISTURE CONTENT: 8%

LOG ADDED AT: Time = 35 minutes

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : JULY 22 1991
RUN : 1
LOC. : STACK

TRAVERSE NO. 1

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
1	0.0	141	0.007	0.60	669.62	88	185	276	38	53	13.0
1	5.0	141	0.008	0.60	671.46	91	207	276	40	53	13.0
1	10.0	144	0.007	0.60	673.44	93	223	280	40	53	12.5
1	15.0	147	0.005	0.60	675.41	97	229	285	40	53	12.5
1	20.0	235	0.005	0.60	677.37	99	237	289	41	54	12.5
1	25.0	294	0.005	0.60	679.33	102	248	272	47	56	12.5
1	30.0	230	0.005	0.60	681.32	103	254	241	51	58	12.5
1	35.0	327	0.008	0.60	683.28	104	253	248	52	60	12.5
1	40.0	354	0.006	0.60	685.21	106	256	250	47	60	12.5
1	45.0	253	0.007	0.60	687.16	107	257	246	46	60	12.5
1	50.0	285	0.006	0.60	689.08	108	257	242	46	61	12.5
1	55.0	352	0.006	0.60	690.95	109	260	243	48	61	12.5
1	60.0	292	0.006	0.60	692.86	109	256	243	49	61	12.5
1	65.0	239	0.005	0.50	694.77	109	253	242	50	61	12.5
1	70.0	241	0.005	0.50	696.68	110	252	243	51	61	12.5
1	75.0	245	0.004	0.50	698.57	110	251	242	52	61	12.5
	80.0				699.21						
		245	0.006	0.58		103	242	257	46	58	12.6

STOVE TYPE: B

WOOD TYPE: MAPLE

TEST START:	17:25
TEST END:	18:41
TEDLAR BAB FILLED AT:	
SAMPLE VOLUME:	0.771 DSm^3
FLUE GAS MOISURE CONTENT:	24%

Note Standard Conditions:	Metric 25 degrees C, 101.3 kPa Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : AUGUST 20 1991
RUN : 1
LOC. : STACK

TRAVERSE NO. 1

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
1	0.0	176	0.014	0.90	925.24	79	250	248	49	77	13.0
1	5.0	169	0.013	0.80	927.80	82	252	251	49	77	13.0
1	10.0	178	0.014	0.70	930.11	86	254	253	48	78	13.2
1	15.0	181	0.014	0.70	932.32	89	252	257	42	78	13.5
1	20.0	178	0.014	0.60	934.42	92	251	256	42	78	13.8
1	25.0	180	0.014	0.60	936.52	94	250	259	41	77	13.9
1	30.0	176	0.013	0.70	938.56	96	255	262	41	76	13.6
1	35.0	164	0.012	0.70	940.67	98	255	262	43	77	13.5
1	40.0	167	0.012	0.70	942.81	98	253	263	41	76	13.5
1	45.0	157	0.012	0.70	944.92	99	256	262	39	76	13.5
1	50.0	153	0.014	0.70	947.18	100	245	263	37	75	13.5
1	55.0	148	0.020	0.70	949.38	100	248	263	38	75	13.3
1	60.0	145	0.014	0.60	951.46	101	244	262	40	76	13.9
1	65.0	159	0.012	0.60	953.53	102	250	262	36	76	13.8
1	70.0	151	0.011	0.60	955.65	101	257	262	36	77	13.7
	75.0				957.80						
		165	0.013	0.69		94	251	259	41	77	13.5

STOVE TYPE: C

WOOD TYPE: MAPLE

TEST START:	18:10
TEST END:	19:25
TEDLAR BAG FILLED AT:	18:50 (Time = 40 minutes)
SAMPLE VOLUME:	0.843 DSm^3
FLUE GAS MOISTURE CONTENT:	13%
LOG ADDED AT:	Time = 55 minutes

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : SEPTEMBER 11 1991
RUN : 1
LOC. : STACK

TRAVERSE NO. 1

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
1	0.0	210	0.013	0.80	259.70	71	163	249	35	61	13.0
1	5.0	217	0.013	0.80	262.14	75	190	249	37	61	13.0
1	10.0	217	0.013	0.80	264.44	79	217	251	35	61	13.0
1	15.0	201	0.013	0.80	266.73	83	241	253	37	55	13.0
1	20.0	215	0.011	0.80	269.02	86	245	255	36	55	13.0
1	25.0	211	0.011	0.80	271.31	89	244	259	36	55	13.0
1	30.0	206	0.011	0.80	273.61	91	244	259	36	55	13.0
1	35.0	198	0.011	0.80	275.93	93	241	261	37	55	13.0
1	40.0	198	0.011	0.80	278.26	95	241	262	37	55	12.8
1	45.0	198	0.012	0.80	280.61	96	241	262	38	56	12.8
1	50.0	216	0.014	0.80	282.91	96	242	262	43	56	13.0
1	55.0	207	0.011	0.70	285.12	97	241	259	44	56	13.0
1	60.0	193	0.010	0.70	287.29	97	240	261	45	57	13.0
1	65.0	216	0.014	0.80	289.54	97	241	262	46	57	13.0
1	70.0	222	0.010	0.80	291.80	98	242	261	47	57	13.0
1	75.0	197	0.010	0.80	294.03	93	224	259	50	59	13.0
1	80.0	187	0.014	0.70	296.38	95	239	258	45	59	13.0
1	85.0	211	0.010	0.60	298.57	95	249	259	46	59	13.5
1	90.0	230	0.005	0.50	300.56	97	255	259	43	59	13.5
1	95.0	206	0.006	0.50	302.44	98	259	260	40	59	13.5
1	100.0	203	0.006	0.50	304.32	99	260	260	38	59	14.0
1	105.0	193	0.008	0.50	306.22	98	259	260	38	58	14.0
1	110.0	218	0.008	0.50	308.14	99	259	260	37	58	14.0
1	115.0	215	0.008	6.00	310.07	100	261	261	37	58	14.0
1	120.0	207	0.007	6.00	312.03	101	260	260	39	58	14.0
1	125.0	199	0.007	6.00	313.98	100	260	260	40	58	14.0
1	130.0	199	0.010	6.00	315.95	101	260	260	41	59	14.0
	135.0				317.87						
		207	0.010	1.50		93	241	259	40	58	13.3

STOVE TYPE: C

WOOD TYPE: MAPLE

TEST START:	11:03
TEST END:	13:24
TEDLAR BAG FILLED AT:	11:58 (Time = 55 minutes)
SAMPLE VOLUME:	1.558 DSm^3
FLUE GAS MOISTURE CONTENT:	14%
LOG ADDED AT:	Time = 40 minutes logs rearranged Time = 45 minutes
DAMPERS ADJUSTED:	Time = 35 minutes air intake open slightly Time = 60 minutes air intake open slightly Time = 65 minutes air intake closed slightly
Note Standard Conditions:	Metric 25 degrees C, 101.3 kPa Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : AUGUST 23 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	148	0.005	0.70	1.77	81	265	230	36	52	13.0
1	5.0	222	0.006	0.70	4.11	84	264	232	36	52	13.0
1	10.0	251	0.005	0.70	6.37	88	268	237	36	52	13.0
1	15.0	241	0.005	0.80	8.65	90	261	243	36	52	13.0
1	20.0	255	0.004	0.80	10.92	93	244	248	36	53	13.0
1	25.0	258	0.004	0.80	13.17	96	252	251	37	53	13.0
1	30.0	251	0.004	0.70	15.43	98	261	254	38	54	13.0
1	35.0	251	0.005	0.80	17.69	99	260	255	37	55	13.0
1	40.0	253	0.005	0.80	19.95	101	261	256	38	55	13.0
1	45.0	248	0.004	0.80	22.19	103	258	258	40	56	12.8
1	50.0	233	0.005	0.80	24.48	103	252	258	38	56	12.8
1	55.0	256	0.003	0.70	26.75	104	263	260	42	56	13.0
1	60.0	240	0.003	0.70	28.94	104	249	259	42	56	13.0
1	65.0	222	0.003	0.70	31.12	105	258	259	39	56	13.0
1	70.0	259	0.005	0.70	33.34	106	254	261	37	58	13.0
	75.0				35.60						
		239	0.004	0.75		97	258	251	38	54	13.0

STOVE TYPE: C

WOOD TYPE: BIRCH

TEST START: 12:15

TEST END: 13:30

TEDLAR BAG FILLED AT: Not specified

SAMPLE VOLUME: 0.893 DSm^3

FLUE GAS MOISTURE CONTENT: 15%

LOG ADDED AT: Time = 50 minutes

DAMPERS ADJUSTED:
Time = 35 minutes air intake opened
Time = 45 minutes air intake opened
Time = 65 minutes logs rearranged and air intake opened

Note Standard Conditions:
Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : AUGUST 26 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	175	0.008	0.80	38.38	85	244	248	43	62	13.0
1	5.0	201	0.007	0.80	40.76	88	255	259	39	62	13.0
1	10.0	192	0.007	0.80	43.11	92	269	260	39	62	13.0
1	15.0	181	0.007	0.80	45.45	95	271	243	41	63	13.0
1	20.0	196	0.007	0.80	47.82	98	264	250	40	63	13.0
1	25.0	186	0.007	0.80	50.19	101	261	250	41	64	12.8
1	30.0	184	0.008	0.80	52.57	103	260	249	42	65	12.8
1	35.0	176	0.006	0.90	54.98	104	257	248	42	65	12.8
1	40.0	185	0.006	0.80	57.35	106	257	248	48	60	13.0
1	45.0	192	0.005	0.80	59.62	107	255	249	44	60	13.0
1	50.0	190	0.005	0.80	61.86	108	263	248	42	60	13.0
1	55.0	184	0.004	0.80	64.11	109	260	248	40	60	13.0
1	60.0	184	0.004	0.80	66.36	109	258	248	40	61	13.0
1	65.0	177	0.004	0.80	68.62	110	256	246	40	62	13.0
1	70.0	173	0.006	0.80	70.85	111	250	247	40	62	13.0
	75.0				73.12						
		185	0.006	0.81		101	259	249	41	62	13.0

STOVE TYPE: C

WOOD TYPE: BIRCH

TEST START:	10:30
TEST END:	11:45
TEDLAR BAG FILLED AT:	11:37 (Time = 70 minutes)
SAMPLE VOLUME:	0.906 DSm^3
FLUE GAS MOISTURE CONTENT:	17%
LOG ADDED AT:	No logs added during test Logs adjusted at: Time = 40 minutes Logs adjusted at: Time = 55 minutes

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : AUGUST 27 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	167	0.007	0.70	74.52	86	236	230	44	70	13.0
1	5.0	170	0.007	0.70	76.81	90	226	230	45	70	13.0
1	10.0	175	0.006	0.70	79.01	93	255	239	44	70	13.0
1	15.0	161	0.006	0.70	81.19	96	262	242	44	70	13.0
1	20.0	159	0.006	0.70	83.37	100	264	243	47	71	13.0
1	25.0	162	0.008	0.70	85.55	103	262	244	49	71	13.0
1	30.0	181	0.008	0.70	87.70	105	260	246	47	71	13.0
1	35.0	185	0.008	0.70	89.85	107	266	247	45	66	13.0
1	40.0	190	0.011	0.70	91.99	108	263	250	46	66	13.0
1	45.0	198	0.010	0.70	94.07	109	264	249	46	66	13.0
1	50.0	187	0.009	0.70	96.22	111	266	251	48	66	13.0
1	55.0	185	0.008	0.70	98.36	112	266	252	49	66	13.0
1	60.0	183	0.008	0.70	100.52	112	260	251	51	66	13.0
1	65.0	177	0.009	0.70	102.66	113	264	252	53	66	13.0
1	70.0	183	0.012	0.70	104.80	113	254	252	56	66	13.0
	75.0				106.90						
		178	0.008	0.70		104	258	245	48	68	13.0

STOVE TYPE: C

WOOD TYPE: PINE

TEST START:	11:30
TEST END:	12:45
TEDLAR BAG FILLED AT:	12:15 (Time = 45 minutes)
SAMPLE VOLUME:	0.850 DSm^3
FLUE GAS MOISTURE CONTENT:	17%
LOG ADDED AT:	No logs added during test
DAMPERS ADJUSTED:	Time = 20 minutes dampers opened Time = 40 minutes dampers closed Time = 60 minutes dampers opened

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT : ENVIRONMENT ONTARIO
JOBSITE : WATERLOO ONTARIO
REF.No. : J2254

DATE : AUGUST 29 1991
RUN : 1
LOC. : STACK

PT. NO.	TIME min.	STACK TEMP. F	VEL. PRES. in.H2O	ORIF. PRES. in.H2O	METER VOL. cu.ft.	MTR. TMP. F	PROB. TEMP. F	OVEN TEMP. F	RES. TMP. F	EXIT TMP. F	PUMP VAC. in.Hg
TRAVERSE NO. 1											
1	0.0	165	0.002	0.80	107.67	83	251	244	43	62	13.0
1	5.0	170	0.002	0.40	109.77	87	230	249	36	62	13.8
1	10.0	166	0.002	0.40	111.45	89	232	251	35	62	13.8
1	15.0	172	0.002	0.30	112.90	93	228	248	35	62	13.8
1	20.0	176	0.002	0.20	114.21	95	264	252	34	63	14.0
1	25.0	178	0.002	0.20	115.49	96	285	255	35	63	15.5
1	30.0	183	0.002	0.20	116.67	100	256	255	36	64	16.2
1	35.0	173	0.002	0.20	117.82	101	264	258	35	64	16.3
1	40.0	175	0.002	0.30	119.08	103	249	259	37	66	16.0
1	45.0	179	0.002	0.40	120.58	105	248	259	40	66	15.5
1	50.0	175	0.002	0.40	122.19	106	255	259	40	66	15.5
	55.0				123.83						
		174	0.002	0.35		96	251	254	37	64	14.9

STOVE TYPE: C

WOOD TYPE: PINE

TEST START:	9:59
TEST END:	10:54
TEDLAR BAG FILLED AT:	Not specified
SAMPLE VOLUME:	0.430 DSm^3
FLUE GAS MOISTURE CONTENT:	15%

NOTE: Whole round logs were used during test instead of split logs. Logs were not burning as intensely as usual. With dampers fully opened the stack temperature was approximately 220°F.

Note Standard Conditions: Metric 25 degrees C, 101.3 kPa
Imperial 77 degrees F, 29.92 in. Hg

APPENDIX D

ANALYTICAL DATA

APPENDIX D-1

ANALYTICAL DATA - ORGANICS

Analytical Data - Stove Type A

SAMPLE NAME	*June 25*					*June 28*					*July 3*				
SAMPLE TYPE	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.
DATE SAMPLED	6/25	6/25	6/25	TOTAL (µg	(µg/m^^3)	6/28	6/28	6/28	TOTAL (µg	(µg/m^^3)	7/03	7/03	7/03	TOTAL (µg	(µg/m^^3)
STOVE TYPE	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
WOOD TYPE	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine
VOLUME (DSCM)				0.664	0.664				0.857	0.857				0.415	0.415
Fluorene	ND	ND	77.9	77.9	117.3	ND	1.4	ND	1.4	1.6	0.3	ND	79.7	80.0	192.8
Dibenzothiophene	ND	ND	0.9	0.9	1.4	ND	ND	ND	0.0	0.0	ND	ND	0.6	0.6	1.5
Phenanthrene	ND	3.6	ND	3.6	5.4	1.4	6.4	1.3	9.2	10.7	35.3	1.6	164.1	201.0	484.5
Anthracene	ND	ND	201.0	201.0	302.8	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Acridine	ND	ND	ND	0.0	0.0	ND	1.9	ND	1.9	2.3	ND	ND	ND	0.0	0.0
Carbazole	ND	ND	1.8	1.8	2.7	ND	3.3	ND	3.3	3.9	ND	0.8	0.4	1.1	2.7
Fluoranthene	ND	8.6	117.2	125.8	189.5	0.6	1.4	0.9	2.9	3.4	8.1	3.5	211.1	222.7	536.6
Pyrene	ND	9.2	347.8	357.0	537.6	ND	0.3	ND	0.3	0.4	5.6	0.0	166.1	171.7	413.7
Retene	ND	1.2	82.3	83.5	125.7	ND	ND	ND	0.0	0.0	ND	ND	0.9	0.9	2.1
Tetracosane	ND	4.5	4.6	9.0	13.6	ND	8.0	ND	8.0	9.3	ND	7.6	1.6	9.2	22.2
Pentacosane	ND	4.5	9.7	14.2	21.4	ND	8.6	ND	8.6	10.0	ND	11.2	1.9	13.1	31.6
Chrysene	ND	31.2	168.3	199.5	300.5	ND	1.8	0.8	2.6	3.0	ND	5.9	53.0	58.9	142.0
1,2-Benzanthranene	ND	36.6	219.5	256.1	385.6	ND	1.4	0.8	2.2	2.6	ND	6.7	70.8	77.5	186.7
Hexacosane	ND	2.9	9.3	12.2	18.4	ND	6.8	101.4	108.2	126.2	ND	9.5	1.0	10.5	25.4
Octacosane	ND	1.7	6.5	8.2	12.3	ND	3.3	0.4	3.7	4.3	ND	10.2	0.5	10.7	25.8
Benzo(b+k)Fluorenthene	ND	141.8	458.6	600.4	904.2	ND	8.1	3.8	11.9	13.9	ND	53.4	103.9	157.3	379.0
Nonacosane	ND	2.2	5.9	8.1	12.2	ND	6.2	0.4	6.6	7.7	ND	8.6	1.3	10.0	24.0
Benzo(e)Pyrene	ND	32.5	90.6	123.1	185.5	ND	1.3	0.5	1.8	2.2	ND	12.9	14.1	27.0	65.1
Benzo(a)Pyrene	ND	47.5	133.8	181.3	273.1	ND	2.6	0.8	3.4	3.9	1.6	17.1	18.6	37.2	89.6
Perylene	ND	11.4	28.5	39.9	60.1	ND	ND	ND	0.0	0.0	ND	3.8	3.7	7.5	18.0
Indeno(1,2,3-c,d)Pyrene	ND	37.1	50.3	87.4	131.6	ND	5.3	0.0	5.3	6.1	3.2	23.6	10.8	37.6	90.6
Dibenzo(a,h)Anthracene	ND	7.0	7.7	14.7	22.1	ND	2.3	ND	2.3	2.7	ND	4.0	1.8	5.7	13.8
Benzo(ghi)Perylene	ND	2.1	47.7	49.8	74.9	ND	0.7	0.3	1.0	1.2	ND	29.0	11.3	40.2	97.0
Surrogate Recoveries (%)															
d10-Phenanthrene	80					81					94				
d12-Chrysene		72	93				72	64				103	101		

Analytical Data - Stove Type A

SAMPLE NAME	August 30					September 3				
SAMPLE TYPE	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.
DATE SAMPLED	8/30	8/30	8/30	TOTAL (µg	(µg/m^^3)	9/03	9/03	9/03	TOTAL (µg	(µg/m^^3)
STOVE TYPE	A	A	A	A	A	A	A	A	A	A
WOOD TYPE	Birch	Birch	Birch	Birch	Birch	Birch	Birch	Birch	Birch	Birch
VOLUME (DSCM)				0.706	0.706				0.917	0.917
Fluorene	ND	ND	45.3	45.3	64.2	ND	ND	64.2	64.2	70.1
Dibenzothiophene	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Phenanthrene	17.0	0.5	ND	17.5	24.8	0.8	1.2	187.0	188.9	206.0
Anthracene	ND	ND	39.3	39.3	55.6	ND	ND	57.9	57.9	63.2
Acridine	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Carbazole	ND	ND	1.0	1.0	1.4	ND	ND	0.6	0.6	0.6
Fluoranthene	5.7	ND	119.0	124.7	176.6	ND	ND	128.3	128.3	139.9
Pyrene	3.1	ND	98.1	101.2	143.3	ND	ND	127.4	127.4	138.9
Retene	ND	ND	8.2	8.2	11.6	ND	ND	0.3	0.3	0.3
Tetracosane	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Pentacosane	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Chrysene	ND	ND	26.5	26.5	37.5	ND	ND	30.6	30.6	33.4
1,2-Benzanthranene	ND	ND	33.2	33.2	47.1	ND	ND	39.4	39.4	43.0
Hexacosane	ND	6.0	ND	6.0	8.5	ND	ND	ND	0.0	0.0
Octacosane	ND	3.0	ND	3.0	4.3	ND	ND	ND	0.0	0.0
Benzo(b+k)Fluorenthene	ND	6.5	54.5	61.0	86.3	ND	6.4	65.6	72.0	78.5
Nonacosane	ND	2.9	ND	2.9	4.1	ND	ND	ND	0.0	0.0
Benzo(e)Pyrene	ND	0.7	15.3	16.0	22.6	ND	0.7	16.4	17.0	18.6
Benzo(a)Pyrene	ND	ND	21.5	21.5	30.5	ND	0.9	24.7	25.6	27.9
Perylene	ND	ND	6.8	6.8	9.6	ND	ND	8.7	8.7	9.5
Indeno(1,2,3-c,d)Pyrene	ND	3.7	19.5	23.2	32.8	ND	6.9	21.8	28.7	31.3
Dibenzo(a,h)Anthracene	ND	0.6	3.7	4.3	6.1	ND	0.8	3.4	4.2	4.5
Benzo(ghi)Perylene	ND	7.6	24.6	32.2	45.6	ND	20.0	27.3	47.4	51.6
Surrogate Recoveries (%)										
d10-Phenanthrene	65	72	80			75	80	66		
d12-Chrysene	68	68	106			67	84	90		

SAMPLE NAME	June 17					September 4					September 10				
SAMPLE TYPE	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.
DATE SAMPLED	6/17	6/17	6/17	TOTAL (µg	(µg/m^^3)	9/04	9/04	9/04	TOTAL (µg	(µg/m^^3)	9/10	9/10	9/10	TOTAL (µg	(µg/m^^3)
STOVE TYPE	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
WOOD TYPE	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple
VOLUME (DSCM)				1.025	1.025				0.735	0.735				0.872	0.872
Fluorene	ND	ND	32.5	32.5	31.7	14.2	ND	258.0	272.1	370.2	ND	ND	174.2	174.2	199.8
Dibenzothiophene	ND	ND	0.4	0.4	0.4	ND	ND	8.5	8.5	11.6	ND	ND	ND	0.0	0.0
Phenanthrene	ND	1.3	236.0	237.3	231.5	96.4	2.8	165.0	264.1	359.3	4.8	ND	161.4	166.2	190.6
Anthracene	ND	ND	37.3	37.3	36.4	ND	ND	ND	0.0	0.0	ND	ND	51.6	51.6	59.1
Acridine	ND	ND	ND	0.0	0.0	ND	ND	441.8	441.8	601.1	ND	ND	ND	0.0	0.0
Carbazole	ND	ND	1.5	1.5	1.4	0.3	ND	8.9	9.2	12.5	ND	ND	3.9	3.9	4.5
Fluoranthene	ND	1.2	141.4	142.6	139.1	8.3	ND	232.1	240.5	327.2	ND	ND	234.3	234.3	268.7
Pyrene	ND	3.0	98.8	101.9	99.4	7.4	ND	535.6	543.0	738.8	ND	ND	282.9	282.9	324.4
Retene	ND	ND	0.4	0.4	0.4	ND	ND	11.3	11.3	15.4	ND	ND	ND	0.0	0.0
Tetracosane	ND	ND	1.8	1.8	1.8	1.2	ND	ND	1.2	1.7	ND	ND	ND	0.0	0.0
Pentacosane	ND	3.3	2.8	6.0	5.9	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Chrysene	ND	ND	23.3	23.3	22.7	ND	49.9	397.7	447.5	608.9	ND	ND	115.7	115.7	132.6
1,2-Benzanthranene	ND	ND	28.7	28.7	28.0	ND	61.7	595.8	657.5	894.5	ND	ND	168.3	168.3	193.1
Hexacosane	ND	ND	1.7	1.7	1.7	ND	ND	ND	0.0	0.0	ND	ND	3.6	3.6	4.1
Octacosane	ND	3.0	0.8	3.8	3.7	ND	ND	ND	0.0	0.0	ND	ND	3.8	3.8	4.4
Benzo(b+k)Fluorenthene	4.3	0.9	57.5	62.7	61.1	0.7	536.3	ND	537.0	730.6	ND	16.8	235.3	252.1	289.1
Nonacosane	ND	1.4	1.2	2.5	2.5	ND	ND	ND	0.0	0.0	ND	ND	3.6	3.6	4.1
Benzo(e)Pyrene	ND	ND	9.1	9.1	8.9	ND	241.7	317.3	559.0	760.6	ND	8.8	67.0	75.9	87.0
Benzo(a)Pyrene	1.5	0.3	12.8	14.6	14.3	ND	426.1	116.3	542.4	738.0	ND	3.2	109.6	112.8	129.4
Perylene	0.2	0.0	2.7	3.0	2.9	ND	114.9	ND	114.9	156.3	ND	3.6	22.6	26.2	30.1
Indeno(1,2,3-c,d)Pyrene	ND	7.4	9.9	17.3	16.9	ND	472.5	225.7	698.2	949.9	ND	35.4	60.9	96.4	110.5
Dibenzo(a,h)Anthracene	ND	ND	1.4	1.4	1.3	ND	98.2	54.6	152.8	207.9	ND	6.4	17.4	23.8	27.3
Benzo(ghi)Perylene	ND	2.3	10.7	13.0	12.7	ND	694.8	246.3	941.1	1280.4	ND	54.7	68.8	123.5	141.6
Surrogate Recoveries (%)															
d10-Phenanthrene	65					74	69	69			86	81	101		
d12-Chrysene		78	95			68	81	93			78	97	106		

Analytical Data - Stove Type B

SAMPLE NAME	August 7					August 12				
SAMPLE TYPE	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.
DATE SAMPLED	8/07	8/07	8/07	TOTAL (µg)	(µg/m^^3)	8/12	8/12	8/12	TOTAL (µg)	(µg/m^^3)
STOVE TYPE	B	B	B	B	B	B	B	B	B	B
WOOD TYPE	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine
VOLUME (DSCM)				1.02	1.02				0.9	0.9
Fluorene	ND	ND	188.3	188.3	184.6	ND	ND	159.2	159.2	176.9
Dibenzothiophene	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Phenanthrene	6.1	2.6	106.5	115.2	112.9	1.5	2.9	50.0	54.4	60.4
Anthracene	ND	ND	20.3	20.3	19.9	ND	ND	ND	0.0	0.0
Acridine	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Carbozole	ND	ND	0.7	0.7	0.7	ND	ND	0.5	0.5	0.6
Fluoranthene	ND	ND	142.3	142.3	139.5	ND	ND	124.9	124.9	138.8
Pyrene	ND	ND	150.5	150.5	147.5	ND	ND	109.1	109.1	121.2
Retene	ND	3.7	472.8	476.5	467.2	ND	4.9	46.5	51.4	57.1
Tetracosane	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Pentacosane	ND	0.6	0.5	1.1	1.1	ND	1.1	0.8	1.9	2.1
Chrysene	ND	9.2	94.2	103.4	101.3	ND	6.3	104.5	110.8	123.1
1,2-Benzanthracene	ND	ND	134.2	134.2	131.6	ND	ND	150.2	150.2	166.9
Hexacosane	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Octacosane	ND	ND	2.1	2.1	2.0	ND	ND	2.2	2.2	2.4
Benzo(b+k)Fluoranthene	ND	64.6	363.7	428.3	419.9	ND	28.4	332.9	361.2	401.4
Nonacosane	ND	ND	0.7	0.7	0.7	ND	ND	0.9	0.9	1.0
Benzo(e)Pyrene	ND	14.6	50.1	64.6	63.4	ND	8.8	46.5	55.3	61.4
Benzo(a)Pyrene	ND	26.5	93.8	120.2	117.9	ND	14.2	66.1	80.3	89.2
Perylene	ND	7.6	18.2	25.8	25.3	ND	4.8	13.8	18.6	20.7
Indeno(1,2,3-c,d)Pyrene	ND	30.1	36.8	66.9	65.6	ND	27.5	31.7	59.2	65.7
Dibenzo(a,h)Anthracene	ND	14.8	14.4	29.2	28.6	ND	14.5	12.7	27.2	30.2
Benzo(ghi)Perylene	ND	37.5	35.1	72.7	71.2	ND	37.7	30.3	68.0	75.6
Surrogate Recoveries (%)										
d10-Phenanthrene	73					73				
d12-Chrysene		88	118				127	117		

Analytical Data - Stove Type B

SAMPLE NAME	July 22					July 24				
SAMPLE TYPE	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.
DATE SAMPLED	7/22	7/22	7/22	TOTAL (µg)	(µg/m^^3)	7/24	7/24	7/24	TOTAL (µg)	(µg/m^^3)
STOVE TYPE	B	B	B	B	B	B	B	B	B	B
WOOD TYPE	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple
VOLUME (DSCM)				0.771	0.771				0.861	0.861
Fluorene	ND	ND	203.1	203.1	263.4	ND	ND	443.3	443.3	514.9
Dibenzothiophene	ND	ND	0.8	0.8	1.0	ND	ND	4.3	4.3	5.0
Phenanthrene	2.8	0.6	252.0	255.4	331.3	8.1	3.4	186.8	198.2	230.2
Anthracene	ND	ND	24.7	24.7	32.1	ND	ND	ND	0.0	0.0
Acridine	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Carbozole	ND	ND	3.5	3.5	4.5	ND	ND	13.8	13.8	16.1
Fluoranthene	6.1	2.2	346.9	355.2	460.7	3.4	10.2	122.0	135.6	157.5
Pyrene	4.5	1.6	185.0	191.1	247.9	3.3	11.6	494.9	509.8	592.1
Retene	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Tetracosane	0.4	1.2	0.6	2.3	2.9	ND	1.7	2.5	4.2	4.9
Pentacosane	ND	3.7	2.0	5.7	7.4	ND	2.3	4.0	6.3	7.3
Chrysene	0.7	3.3	82.8	86.8	112.6	ND	17.6	251.2	268.8	312.2
1,2-Benzanthracene	0.7	4.5	112.8	118.1	153.2	ND	19.5	275.9	295.4	343.1
Hexacosane	ND	3.6	ND	3.6	4.6	ND	2.1	8.3	10.4	12.1
Octacosane	ND	1.8	0.5	2.3	3.0	ND	1.9	1.1	2.9	3.4
Benzo(b+k)Fluoranthene	0.4	57.4	258.1	315.9	409.7	ND	115.5	491.0	606.5	704.4
Nonacosane	ND	2.0	1.0	3.1	4.0	ND	1.7	1.0	2.7	3.1
Benzo(e)Pyrene	ND	15.6	63.0	78.6	101.9	ND	30.2	63.6	93.8	108.9
Benzo(a)Pyrene	ND	29.5	80.8	110.3	143.1	ND	62.5	158.7	221.2	256.9
Perylene	ND	8.1	14.7	22.7	29.5	ND	14.1	26.3	40.4	47.0
Indeno(1,2,3-c,d)Pyrene	ND	35.4	22.2	57.5	74.6	ND	41.4	49.4	90.8	105.4
Dibenzo(a,h)Anthracene	ND	13.3	8.7	22.0	28.6	ND	14.6	16.3	31.0	36.0
Benzo(ghi)Perylene	ND	44.0	18.7	62.7	81.3	ND	55.8	53.4	109.2	126.9
Surrogate Recoveries (%)										
d10-Phenanthrene	99					89				
d12-Chrysene		58	121				70	147		

Analytical Data - Stove Type B

SAMPLE NAME	*July 30*					*August 1*				
SAMPLE TYPE	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.
DATE SAMPLED	7/30	7/30	7/30	TOTAL (µg)	(µg/m^^3)	8/01	8/01	8/01	TOTAL (µg)	(µg/m^^3)
STOVE TYPE	B	B	B	B	B	B	B	B	B	B
WOOD TYPE	Birch	Birch	Birch	Birch	Birch	Birch	Birch	Birch	Birch	Birch
VOLUME (DSCM)				1.124	1.124				0.977	0.977
Fluorene	ND	100.4	269.4	369.7	328.9	ND	ND	252.2	252.2	258.1
Dibenzothiophene	ND	4.2	1.5	5.7	5.1	ND	ND	ND	0.0	0.0
Phenanthrene	10.6	418.3	240.9	669.8	595.9	4.6	2.8	49.3	56.6	57.9
Anthracene	ND	113.1	ND	113.1	100.6	ND	ND	ND	0.0	0.0
Acridine	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Carbozole	ND	4.3	2.5	6.9	6.1	ND	ND	0.8	0.8	0.8
Fluoranthene	3.1	361.9	109.6	474.6	422.2	ND	2.7	138.2	140.9	144.2
Pyrene	3.1	359.9	249.5	612.6	545.0	ND	1.9	335.5	337.5	345.4
Retene	ND	16.6	2.6	19.2	17.1	ND	3.7	35.9	39.6	40.6
Tetracosane	ND	0.4	1.3	1.7	1.6	ND	2.4	ND	2.4	2.5
Pentacosane	ND	5.9	46.6	52.5	46.7	ND	0.2	1.0	1.2	1.2
Chrysene	ND	106.3	65.9	172.2	153.2	ND	20.5	153.6	174.0	178.1
1,2-Benzanthracene	ND	141.9	88.9	230.8	205.4	ND	12.0	226.2	238.2	243.8
Hexacosane	ND	1.2	7.0	8.3	7.4	ND	ND	0.6	0.6	0.6
Octacosane	ND	ND	8.2	8.2	7.3	ND	ND	2.2	2.2	2.3
Benzo(b+k)Fluoranthene	ND	341.2	143.7	484.9	431.4	0.1	139.3	87.5	226.9	232.3
Nonacosane	ND	1.4	5.7	7.1	6.3	ND	ND	1.3	1.3	1.4
Benzo(e)Pyrene	ND	75.4	19.6	95.0	84.5	ND	27.3	60.5	87.9	89.9
Benzo(a)Pyrene	ND	137.8	45.7	183.6	163.3	ND	47.9	105.1	153.0	156.6
Perylene	ND	29.3	8.9	38.2	33.9	ND	13.0	20.1	33.2	34.0
Indeno(1,2,3-c,d)Pyrene	ND	66.4	19.6	86.0	76.5	ND	42.4	46.4	88.8	90.9
Dibenzo(a,h)Anthracene	ND	20.7	7.4	28.2	25.1	ND	18.3	17.5	35.8	36.6
Benzo(ghi)Perylene	ND	85.0	22.3	107.3	95.5	ND	53.7	48.3	101.9	104.3
Surrogate Recoveries (%)										
d10-Phenanthrene	99					78				
d12-Chrysene		90	114				102	121		

Analytical Data - Stove Type C

SAMPLE NAME	August 20					September 11				
SAMPLE TYPE	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.
DATE SAMPLED	8/20	8/20	8/20	TOTAL (µg)	(µg/m^^3)	9/11	9/11	9/11	TOTAL (µg)	(µg/m^^3)
STOVE TYPE	C	C	C	C	C	C	C	C	C	C
WOOD TYPE	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple	Maple
VOLUME (DSCM)				0.843	0.843				1.558	1.558
Fluorene	7.1	ND	254.0	261.1	309.7	5.3	ND	333.8	339.1	217.6
Dibenzothiophene	ND	ND	4.1	4.1	4.9	ND	ND	3.8	3.8	2.4
Phenanthrene	104.5	ND	ND	104.5	124.0	52.8	1.8	161.8	216.5	138.9
Anthracene	11.8	ND	264.7	276.5	327.9	14.4	ND	198.9	213.3	136.9
Acridine	ND	ND	ND	0.0	0.0	ND	ND	263.1	263.1	168.9
Carbazole	ND	ND	ND	0.0	0.0	0.0	ND	23.5	23.6	15.1
Fluoranthene	17.5	ND	271.5	289.1	342.9	5.6	ND	262.4	268.0	172.0
Pyrene	14.8	ND	295.0	309.9	367.6	4.3	ND	253.3	257.6	165.3
Retene	ND	ND	10.3	10.3	12.2	ND	ND	51.8	51.8	33.3
Tetracosane	6.6	ND	ND	6.6	7.9	ND	ND	ND	0.0	0.0
Pentacosane	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Chrysene	ND	ND	333.5	333.5	395.6	ND	16.2	445.2	461.3	296.1
1,2-Benzanthracene	ND	ND	47.6	47.6	56.5	ND	13.7	667.7	681.4	437.3
Hexacosane	ND	ND	6.5	6.5	7.7	ND	ND	29.9	29.9	19.2
Octacosane	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Benzo(b+k)Fluoranthene	ND	13.0	163.9	176.8	209.8	ND	165.1	501.2	666.3	427.7
Nonacosane	ND	ND	ND	0.0	0.0	ND	ND	0.6	0.6	0.4
Benzo(e)Pyrene	0.4	9.5	250.7	260.6	309.1	ND	72.4	ND	72.4	46.5
Benzo(a)Pyrene	ND	16.5	52.5	69.0	81.9	ND	141.2	145.8	287.0	184.2
Perylene	ND	3.5	93.0	96.5	114.4	ND	42.3	ND	42.3	27.2
Indeno(1,2,3-c,d)Pyrene	ND	41.8	188.8	230.6	273.5	ND	240.2	400.8	641.0	411.4
Dibenzo(a,h)Anthracene	ND	7.6	45.4	53.0	62.9	ND	50.5	92.3	142.9	91.7
Benzo(ghi)Perylene	ND	72.0	205.4	277.4	329.1	ND	434.6	494.1	928.7	596.1
Surrogate Recoveries (%)										
d10-Phenanthrene	77	65	70			89	84	65		
d12-Chrysene	114	81	104			84	114	56		

Analytical Data - Stove Type C

SAMPLE NAME	August 23					August 26				
SAMPLE TYPE	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.
DATE SAMPLED	8/23	8/23	8/23	TOTAL (µg)	(µg/m^^3)	8/26	8/26	8/26	TOTAL (µg)	(µg/m^^3)
STOVE TYPE	C	C	C	C	C	C	C	C	C	C
WOOD TYPE	Birch	Birch	Birch	Birch	Birch	Birch	Birch	Birch	Birch	Birch
VOLUME (DSCM)				0.893	0.893				0.906	0.906
Fluorene	ND	ND	31.8	31.8	35.6	2.9	ND	121.6	124.5	137.5
Dibenzothiophene	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Phenanthrene	0.9	1.1	83.4	85.4	95.6	44.5	ND	152.3	196.7	217.2
Anthracene	ND	ND	ND	0.0	0.0	ND	ND	53.3	53.3	58.8
Acridine	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Carbazole	ND	ND	2.0	2.0	2.3	ND	ND	3.2	3.2	3.5
Fluoranthene	ND	ND	174.2	174.2	195.1	1.4	ND	193.4	194.8	215.0
Pyrene	ND	ND	164.0	164.0	183.6	ND	ND	287.6	287.6	317.5
Retene	ND	ND	14.0	14.0	15.7	ND	ND	4.1	4.1	4.6
Tetracosane	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Pentacosane	ND	8.0	ND	8.0	8.9	ND	ND	ND	0.0	0.0
Chrysene	ND	ND	93.0	93.0	104.2	ND	ND	126.4	126.4	139.5
1,2-Benzanthracene	ND	ND	151.1	151.1	169.3	ND	ND	184.6	184.6	203.8
Hexacosane	ND	7.2	ND	7.2	8.1	ND	ND	ND	0.0	0.0
Octacosane	ND	4.2	ND	4.2	4.7	ND	ND	ND	0.0	0.0
Benzo(b+k)Fluoranthene	ND	78.9	158.8	237.6	266.1	ND	22.4	263.3	285.7	315.4
Nonacosane	ND	1.0	ND	1.0	1.2	ND	ND	ND	0.0	0.0
Benzo(e)Pyrene	ND	37.5	35.2	72.7	81.4	ND	11.8	89.0	100.8	111.3
Benzo(a)Pyrene	ND	68.9	86.6	155.5	174.2	ND	5.3	135.1	140.4	155.0
Perylene	ND	19.6	14.2	33.8	37.8	ND	5.7	26.4	32.1	35.5
Indeno(1,2,3-c,d)Pyrene	ND	91.4	14.1	105.4	118.1	ND	52.9	59.9	112.8	124.5
Dibenzo(a,h)Anthracene	ND	20.2	3.8	24.0	26.9	ND	9.3	17.6	26.9	29.7
Benzo(ghi)Perylene	ND	126.5	9.1	135.6	151.9	ND	84.1	64.6	148.7	164.1
Surrogate Recoveries (%)										
d10-Phenanthrene	87	80	79			70	62	101		
d12-Chrysene	83	105	80			66	110	102		

SAMPLE NAME	*August 27*					*August 29*				
SAMPLE TYPE	Water	Filter	XAD-2		CONC.	Water	Filter	XAD-2		CONC.
DATE SAMPLED	8/27	8/27	8/27	TOTAL (µg)	(µg/m^^3)	8/29	8/29	8/29	TOTAL (µg)	(µg/m^^3)
STOVE TYPE	C	C	C	C	C	C	C	C	C	C
WOOD TYPE	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine	Pine
VOLUME (DSCM)				0.851	0.851				0.430	0.430
Fluorene	ND	ND	32.3	32.3	37.9	7.9	20.5	385.5	413.9	962.6
Dibenzothiophene	ND	ND	ND	0.0	0.0	ND	ND	15.7	15.7	36.6
Phenanthrene	ND	ND	ND	0.0	0.0	41.5	333.2	ND	374.7	871.3
Anthracene	ND	ND	34.2	34.2	40.2	9.4	93.1	384.2	486.7	1131.8
Acridine	ND	ND	ND	0.0	0.0	ND	ND	196.3	196.3	456.5
Carbazole	ND	ND	0.3	0.3	0.4	ND	0.1	84.3	84.5	196.4
Fluoranthene	ND	ND	91.6	91.6	107.6	0.0	517.3	21.4	538.7	1252.9
Pyrene	ND	ND	58.4	58.4	68.6	ND	515.8	338.2	854.0	1986.0
Retene	ND	ND	43.4	43.4	51.1	3.8	950.4	208.4	1162.6	2703.7
Tetracosane	ND	ND	ND	0.0	0.0	ND	ND	6.7	6.7	15.7
Pentacosane	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Chrysene	ND	ND	34.9	34.9	41.1	ND	310.1	359.4	669.6	1557.2
1,2-Benzanthracene	ND	ND	46.0	46.0	54.1	ND	323.2	537.8	861.0	2002.4
Hexacosane	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Octacosane	ND	ND	ND	0.0	0.0	ND	ND	ND	0.0	0.0
Benzo(b+k)Fluoranthene	ND	7.0	34.8	41.8	49.1	ND	436.2	ND	436.2	1014.5
Nonacosane	ND	3.1	ND	3.1	3.6	ND	ND	ND	0.0	0.0
Benzo(e)Pyrene	ND	0.9	7.9	8.8	10.3	ND	124.6	121.2	245.8	571.6
Benzo(a)Pyrene	ND	1.2	1.7	2.9	3.4	ND	298.1	111.0	409.1	951.5
Perylene	ND	ND	1.8	1.8	2.1	ND	63.5	ND	63.5	147.7
Indeno(1,2,3-c,d)Pyrene	ND	9.5	4.3	13.8	16.3	ND	160.3	73.1	233.5	543.0
Dibenzo(a,h)Anthracene	ND	1.2	1.2	2.4	2.8	ND	63.4	32.9	96.3	223.9
Benzo(ghi)Perylene	ND	3.4	4.6	8.0	9.4	ND	145.6	58.1	203.7	473.7
Surrogate Recoveries (%)										
d10-Phenanthrene	63	64	64			71	89	83		
d12-Chrysene	57	112	101			68	68	106		

APPENDIX D-2

ANALYTICAL DATA - INORGANICS

EPL
ENVIRONMENTAL
PROTECTION
LABORATORIES INC

Client:	Concord Environmental 2 Tippett Rd. Toronto, Ontario M3H 2V2	EPL Ref. #:	912074
		Client Ref. #:	J2254 (R80)
		Date Submitted:	Sept. 18/91
		Date Reported:	Oct. 7/91

Attn: Donna L. Dougherty

CERTIFICATE OF ANALYSIS

Analysis Performed: Determination of trace metals on air sampling filters.

Methodology: Metals: Preparation - Adaption of NIOSH Method 7800
Analysis - U.S. EPA Method 6010

Instrumentation: Thermo Jarrell Ash ICAP 61E Plasma Spectrophotometer

Sample Description: Filters

Results: Refer to the accompanying tables.

Geldart
Certified by
V. Geldart, B.Sc.
Service Manager

ASSOCIATION OF THE CHEMICAL PROFESSION OF ONTARIO
CHARTERED
T. Munshaw
CHEMIST

Certified by
T. Munshaw, M.Sc., C.Chem
Vice President, Laboratory Services

ENVIRONMENT PROTECTION LABORATORIES INC.

REPORT OF ANALYSIS

Client: Concord Environmental | Ref #: J2254 (R80) | EPL #: 912074

Sample Matrix: Filters | Concentration Units: ug/sample (sample = 1/2 filter)

Parameter	LOQ	June 25 ~~June 5/91~~ 6697	Aug. 20/91 6698	Aug. 22/91 6699	Aug. 23/91 6700	Aug. 26/91 6701
Silver	0.2	nd	nd	nd	nd	nd
Aluminum	0.6	71	512	628	1510	210
Bismuth	1.5	nd	nd	nd	nd	nd
Boron	0.3	64.8	715	845	1820	431
Barium	0.05	8.77	1020	1220	2900	589
Beryllium	0.1	nd	nd	nd	0.5	nd
Cadmium	0.08	1.24	1.06	2.91	8.80	3.73
Calcium	2.5	413	352	805	232	607
Cobalt	0.1	nd	1.4	1.8	1.7	1.0
Chromium	0.1	0.4	0.5	0.6	0.8	0.4
Copper	0.08	0.72	3.67	1.89	1.86	2.75
Iron	0.1	5.7	12.6	18.3	20.6	8.5
Potassium	40	2230	3240	1510	2820	3330
Manganese	0.1	1.7	3.8	2.3	10.9	8.1
Molybdenum	0.3	0.4	nd	nd	nd	nd
Nickel	0.3	0.4	5.5	nd	0.7	nd
Lead	0.3	7.1	8.7	6.3	21.7	26.1
Tin	1.5	nd	nd	19.7	nd	nd
Titanium	1.5	nd	nd	nd	nd	nd
Vanadium	0.3	nd	nd	nd	nd	nd
Zinc	0.1	51.0	842	919	2870	1350

Authorization I.D.: ____________________

LOQ = limit of quantitation = lowest level of the parameter that can be quantitated with confidence.
nd = parameter not detected.
[illegible]

ENVIRONMENT PROTECTION LABORATORIES INC.

REPORT OF ANALYSIS

Client: Concord Environmental   Ref #: J2254 (R80)   EPL #: 912074

Sample Matrix: Filters   `Concentration Units: ug/sample (sample = 1/2 filter)`

Parameter	LOQ	Aug. 27/91 6702	Aug. 29/91 6703	Aug. 30/91 6704	Sept. 3/91 6705	Sept. 4/91 6706
Silver	0.2	nd	nd	nd	nd	nd
Aluminum	0.6	946	227	132	559	979
Bismuth	1.5	nd	nd	nd	nd	nd
Boron	0.3	1280	308	234	683	1040
Barium	0.05	1810	444	283	1060	1820
Beryllium	0.1	0.3	nd	nd	nd	0.3
Cadmium	0.08	2.54	0.59	2.69	7.03	6.04
Calcium	2.5	607	217	245	337	515
Cobalt	0.1	0.7	0.5	nd	nd	nd
Chromium	0.1	0.7	0.3	nd	0.7	0.9
Copper	0.08	0.72	nd	0.35	2.89	0.54
Iron	0.1	13.7	4.4	3.4	15.3	11.9
Potassium	40	1700	757	1180	1370	2060
Manganese	0.1	13.6	0.8	1.2	4.5	2.3
Molybdenum	0.3	nd	nd	nd	nd	nd
Nickel	0.3	0.7	nd	nd	1.1	2.1
Lead	0.3	4.4	0.5	10.9	33.4	13.0
Tin	1.5	nd	nd	nd	nd	nd
Titanium	1.5	nd	nd	nd	nd	nd
Vanadium	0.3	nd	nd	nd	nd	nd
Zinc	0.1	1290	352	399	1820	1370

Authorization I.D.: ____________

LOQ = limit of quantitation = lowest level of the parameter that can be quantitated with confidence.
nd = parameter not detected.
074META1/WL

ENVIRONMENT PROTECTION LABORATORIES INC.

REPORT OF ANALYSIS

Client: Concord Environmental   Ref #: J2254 (R80)   EPL #: 912074

Sample Matrix: Filters   Concentration Units: ug/sample (sample = 1/2 filter)

Parameter	LOQ	Sept. 10/91 6707	Sept. 11/91 6708	Blank 1 6709	Blank 2 6710	Blank 3 6711
Silver	0.2	nd	nd	nd	nd	nd
Aluminum	0.6	694	132	300	948	502
Bismuth	1.5	nd	nd	nd	nd	nd
Boron	0.3	784	223	298	1090	665
Barium	0.05	1310	280	584	1770	995
Beryllium	0.1	nd	nd	nd	0.3	nd
Cadmium	0.08	5.87	1.77	nd	nd	nd
Calcium	2.5	428	206	185	516	291
Cobalt	0.1	nd	nd	nd	nd	nd
Chromium	0.1	0.9	nd	nd	0.3	0.5
Copper	0.08	0.58	0.89	nd	nd	nd
Iron	0.1	11.6	2.5	3.5	10.8	6.4
Potassium	40	2260	4420	504	1180	713
Manganese	0.1	2.8	2.8	nd	0.5	0.3
Molybdenum	0.3	nd	nd	nd	nd	nd
Nickel	0.3	0.6	0.3	nd	0.4	0.4
Lead	0.3	19.6	6.0	0.4	1.9	1.3
Tin	1.5	nd	nd	nd	nd	nd
Titanium	1.5	nd	nd	nd	nd	nd
Vanadium	0.3	nd	nd	nd	nd	nd
Zinc	0.1	1260	289	434	1210	705

Authorization I.D.:

LOQ = limit of quantitation = lowest level of the parameter that can be quantitated with confidence.
nd = parameter not detected.

ENVIRONMENT PROTECTION LABORATORIES INC.

REPORT OF ANALYSIS

Client: Concord Environmental **Ref #:** J2254 (R80) **EPL #:** 912074

Sample Matrix: Filters `Concentration Units: ug/sample (sample = 1/2 filter)`

Parameter	LOQ	Blank 4 6712	Replicate June 5/91 - 6697	Replicate Blank 4 - 6712
Silver	0.2	nd	nd	nd
Aluminum	0.6	686	73.0	724
Bismuth	1.5	nd	nd	nd
Boron	0.3	860	70.3	919
Barium	0.05	1360	8.70	1440
Beryllium	0.1	nd	nd	nd
Cadmium	0.08	nd	1.21	nd
Calcium	2.5	628	485	731
Cobalt	0.1	nd	nd	nd
Chromium	0.1	0.7	0.4	0.6
Copper	0.08	0.28	0.78	0.17
Iron	0.1	9.7	5.2	10.0
Potassium	40	1410	2580	1590
Manganese	0.1	0.4	0.4	0.5
Molybdenum	0.3	nd	nd	nd
Nickel	0.3	nd	nd	0.3
Lead	0.3	1.6	7.2	1.1
Tin	1.5	nd	nd	nd
Titanium	1.5	nd	nd	nd
Vanadium	0.3	nd	nd	nd
Zinc	0.1	908	51.9	965

Authorization I.D.: ________________

LOQ = limit of quantitation = lowest level of the parameter that can be quantitated with confidence.
nd = parameter not detected.
074METALS/WL

ENVIRONMENT PROTECTION LABORATORIES

CERTIFICATE OF QUALITY CONTROL

Client: Concord Environmental
Ref #: J2254 (R80)
EPL #: 912074

Sample Type: Filter
Concentration Units: mg/L

Parameters	LOQ	Method Blank	LAB SRM	ACT SRM	% L/A	L.L. - U.L. (%)	Matrix Spike (%)*	Acceptable
Silver	0.003	nd	0.99	1.00	99.0	90 - 110	-	Yes
Aluminum	0.025	nd	0.98	1.00	98.0	90 - 110	-	Yes
Boron	0.01	nd	0.98	1.00	98.0	90 - 110	112/221	Yes
Barium	0.002	nd	0.97	1.00	97.0	90 - 110	-	Yes
Beryllium	0.005	nd	0.96	1.00	96.0	90 - 110	107/180	Yes
Calcium	0.01	nd	0.94	1.00	94.0	90 - 110	-	Yes
Cadmium	0.003	nd	1.01	1.00	101	90 - 110	108/108	Yes
Cobalt	0.005	nd	0.98	1.00	98.0	90 - 110	107/107	Yes
Chromium	0.005	nd	1.01	1.00	101	90 - 110	109/107	Yes
Copper	0.002	nd	0.99	1.00	99.0	90 - 110	109/109	Yes
Iron	0.005	nd	1.01	1.00	101	90 - 110	112/110	Yes
Potassium	0.4	nd	5.0	5.0	100	90 - 110	-	Yes
Manganese	0.005	nd	1.01	1.00	101	90 - 110	108/108	Yes
Molybdenum	0.01	nd	1.04	1.00	104	90 - 110	-	Yes
Nickel	0.01	nd	1.06	1.00	106	90 - 110	108/108	Yes
Lead	0.02	nd	0.99	1.00	99.0	90 - 110	119/108	Yes
Vanadium	0.01	nd	0.97	1.00	97.0	90 - 110	-	Yes
Zinc	0.005	nd	0.98	1.00	98.0	90 - 110	117/233	Yes

Authorization I.D.:

LOQ = limit of quantitation = lowest level of the parameter that can be quantitated with confidence.
nd = parameter not detected
- = not applicable
* = on client sample June 5/91 6697 and Blank 4 6712
SRM = Standard Reference Material
LAB = Laboratory Generated Value
ACT = Accepted Actual Value
L/A = Ratio of LAB value to ACT value
L.L. = Lower Control Limit
U.L. = Upper Control Limit

SRM I.D. = U.S. EPA ICAP-19/7 WP 988
U.S. EPA Trace Metal-AA TMA 989
NBS Multielement Mix A 3171
NBS Multielement Mix B 3172

Note = All results have been corrected from blank interferences.

074METQ/WL

EPL
ENVIRONMENT
PROTECTION
LABORATORIES INC.

Client:	Concord Environmental 2 Tippett Rd. Toronto, Ontario M3H 2V2	EPL Ref. #:	911940
		Client Ref. #:	J2254
		Date Submitted:	Aug. 28/91
		Date Reported:	Sept. 10/91

Attn: Donna L. Dougherty

CERTIFICATE OF ANALYSIS

Analysis Performed: Determination of trace metals on air sampling filters.

Methodology: Metals: Preparation - Adaption of NIOSH Method 7800
Analysis - U.S. EPA Method 6010

Instrumentation: Thermo Jarrell Ash ICAP 61E Plasma Spectrophotometer

Sample Description: Filters

Results: Refer to the accompanying tables.

V. Geldart
Certified by
V. Geldart, B.Sc
Service Manager

Certified by T. Munshaw
T. Munshaw, M.Sc., C.Chem
Vice President, Laboratory Services

ASSOCIATION OF THE CHEMICAL PROFESSION OF ONTARIO
CHARTERED CHEMIST
T. Munshaw

940METC/NL

ENVIRONMENT PROTECTION LABORATORIES INC.

REPORT OF ANALYSIS

Client: Concord Environmental   Ref #: J2254   EPL #: 911940

Sample Matrix: Filters   `Concentration Units: ug/sample (sample = 1/2 filter)`

Parameter	LOQ	July 25 6696	June 28 6695	July 22 6694	July 24 6693	July 30 6692
Silver	0.2	0.2	0.2	0.2	nd	nd
Aluminum	0.6	261	193	164	424	389
Bismuth	1.5	nd	nd	nd	nd	nd
Boron	0.3	567	420	445	840	813
Barium	0.05	775	563	518	1130	1100
Beryllium	0.1	nd	nd	nd	nd	nd
Cadmium	0.08	1.15	1.36	1.07	2.65	3.55
Calcium	2.5	303	260	141	357	339
Cobalt	0.1	nd	nd	nd	1.2	1.8
Chromium	0.1	0.6	0.7	0.5	0.8	0.6
Copper	0.08	1.21	0.83	0.81	0.90	0.52
Iron	0.1	4.6	4.7	4.7	11.7	10.6
Potassium	40	1130	970	3130	2610	1030
Manganese	0.1	3.9	8.1	1.0	1.8	5.9
Molybdenum	0.3	nd	nd	nd	nd	nd
Nickel	0.3	nd	nd	nd	nd	nd
Lead	0.3	2.6	2.7	3.4	11.8	9.5
Tin	1.5	nd	nd	nd	nd	nd
Titanium	1.5	nd	nd	nd	nd	nd
Vanadium	0.3	nd	nd	nd	nd	nd
Zinc	0.1	618	503	388	887	954

Authorization I.D.:

LOQ = limit of quantitation = lowest level of the parameter that can be quantitated with confidence.
nd = parameter not detected.
940METAVML

ENVIRONMENT PROTECTION LABORATORIES INC.

REPORT OF ANALYSIS

Client: Concord Environmental   Ref #: J2254   EPL #: 911940

Sample Matrix: Filters   Concentration Units: ug/sample (sample = 1/2 filter)

Parameter	LOQ	Aug. 1 6691	Aug. 7 6690	Aug. 12 6689	Blank 6688	Replicate June 25 6696
Silver	0.2	nd	0.7	0.2	nd	nd
Aluminum	0.6	452	279	549	186	280
Bismuth	1.5	nd	nd	nd	nd	nd
Boron	0.3	784	625	963	445	574
Barium	0.05	1100	811	1340	499	747
Beryllium	0.1	nd	nd	nd	nd	nd
Cadmium	0.08	7.12	1.01	1.42	nd	1.28
Calcium	2.5	418	333	431	134	282
Cobalt	0.1	2.9	2.6	1.9	nd	nd
Chromium	0.1	0.7	0.5	0.8	0.5	0.6
Copper	0.08	1.43	0.61	0.85	0.21	1.35
Iron	0.1	13.9	9.5	10.3	2.2	5.3
Potassium	40	2930	990	1720	295	1300
Manganese	0.1	9.5	10.4	4.3	nd	4.3
Molybdenum	0.3	nd	nd	nd	nd	nd
Nickel	0.3	nd	nd	nd	nd	nd
Lead	0.3	16.8	3.1	4.6	1.5	3.0
Tin	1.5	nd	nd	nd	nd	nd
Titanium	1.5	nd	nd	nd	nd	nd
Vanadium	0.3	nd	nd	nd	nd	nd
Zinc	0.1	1290	643	1030	317	632

Authorization I.D.:

LOQ = limit of quantitation = lowest level of the parameter that can be quantitated with confidence.
nd = parameter not detected.

ENVIRONMENT PROTECTION LABORATORIES

CERTIFICATE OF QUALITY CONTROL

Client: Concord Environmental **Ref #:** J2254 **EPL #:** 911940

Sample Type: Filter **Concentration Units:** mg/L

Parameters	LOQ	Method Blank	LAB SRM	ACT SRM	% L/A	L.L. - U.L. (%)	Matrix Spike (%)*	Acceptable
Silver	0.003	nd	0.96	1.00	96.0	90 - 110	-	Yes
Aluminum	0.025	nd	0.97	1.00	97.0	90 - 110	-	Yes
Boron	0.01	nd	0.97	1.00	97.0	90 - 110	109	Yes
Barium	0.002	nd	0.97	1.00	97.0	90 - 110	-	Yes
Beryllium	0.005	nd	0.94	1.00	94.0	90 - 110	113	Yes
Calcium	0.01	nd	0.96	1.00	96.0	90 - 110	-	Yes
Cadmium	0.003	nd	0.99	1.00	99.0	90 - 110	113	Yes
Cobalt	0.005	nd	0.96	1.00	96.0	90 - 110	113	Yes
Chromium	0.005	nd	0.99	1.00	99.0	90 - 110	113	Yes
Copper	0.002	nd	0.98	1.00	98.0	90 - 110	113	Yes
Iron	0.005	nd	0.96	1.00	96.0	90 - 110	110	Yes
Potassium	0.4	nd	4.7	5.0	94.0	90 - 110	-	Yes
Manganese	0.005	nd	1.00	1.00	100	90 - 110	110	Yes
Molybdenum	0.01	nd	1.04	1.00	104	90 - 110	-	Yes
Nickel	0.01	nd	0.99	1.00	99.0	90 - 110	113	Yes
Lead	0.02	nd	0.97	1.00	97.0	90 - 110	114	Yes
Vanadium	0.01	nd	0.97	1.00	97.0	90 - 110	-	Yes
Zinc	0.005	nd	0.96	1.00	96.0	90 - 110	115	Yes

Authorization I.D.: ____________________

LOQ = limit of quantitation = lowest level of the parameter that can be quantitated with confidence.

nd = parameter not detected

– = not applicable

* = on client sample June 25 6696

SRM = Standard Reference Material

LAB = Laboratory Generated Value

ACT = Accepted Actual Value

L/A = Ratio of LAB value to ACT value

L.L. = Lower Control Limit

U.L. = Upper Control Limit

SRM I.D. = U.S. EPA ICAP-19/7 WP 988
U.S. EPA Trace Metal-AA TMA 989
NBS Multielement Mix A 3171
NBS Multielement Mix B 3172

Note = All results have been corrected from blank interferences.

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CONCORD ENVIRONMENTAL PAH EMISSION REPORT

CLIENT  : ENVIRONMENT ONTARIO                          DATE : JULY 22 1991
JOBSITE : WATERLOO ONTARIO                             RUN  : 1
REF.No. : J2254                                        LOC. : STACK


PT. TIME  STACK   VEL.   ORIF.  METER   MTR. PROB. OVEN  RES. EXIT  PUMP
NO.       TEMP.  PRES.   PRES.   VOL.   TMP. TEMP. TEMP. TMP. TMP.  VAC.
     min.   F   in.H2O in.H2O  cu.ft.    F     F     F     F    F   in.Hg
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TRAVERSE NO.  1

 1    0.0  141   0.007  0.60   669.62    88   185   276   38   53  13.0
 1    5.0  141   0.008  0.60   671.46    91   207   276   40   53  13.0
 1   10.0  144   0.007  0.60   673.44    93   223   280   40   53  12.5
 1   15.0  147   0.005  0.60   675.41    97   229   285   40   53  12.5
 1   20.0  235   0.005  0.60   677.37    99   237   289   41   54  12.5
 1   25.0  294   0.005  0.60   679.33   102   248   272   47   56  12.5
 1   30.0  230   0.005  0.60   681.32   103   254   241   51   58  12.5
 1   35.0  327   0.008  0.60   683.28   104   253   248   52   60  12.5
 1   40.0  354   0.006  0.60   685.21   106   256   250   47   60  12.5
 1   45.0  253   0.007  0.60   687.16   107   257   246   46   60  12.5
 1   50.0  285   0.006  0.60   689.08   108   257   242   46   61  12.5
 1   55.0  352   0.006  0.60   690.95   109   260   243   48   61  12.5
 1   60.0  292   0.006  0.60   692.86   109   256   243   49   61  12.5
 1   65.0  239   0.005  0.50   694.77   109   253   242   50   61  12.5
 1   70.0  241   0.005  0.50   696.68   110   252   243   51   61  12.5
 1   75.0  245   0.004  0.50   698.57   110   251   242   52   61  12.5
     80.0                      699.21

           245   0.006  0.58            103   242   257   46   58  12.6
```